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Evaluation And Comparison Of Surface Characteristic Of Orthodontic Temporary Anchorage Device Following Electrochemical Anodization- An In Vitro Study

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Abstract:

Introduction: Orthodontic treatment hinges on the anchorage protocol planned for a particular case. The immediate or early loading protocol used routinely in miniscrews therapy will not allow sufficient time for bone to relieve these insertion stresses by remodelling or other relaxation mechanism. Hence, modifications of the osseointegration into orthodontic mechanics was improvised based on experiences with interdisciplinary dentistry.

Materials and Methods: The sample used in the study included 80 mini-screws of JSV Orthodontics^{TM}. The screws were placed as anode in the electrolytic cell using alligator clips whereas aluminium bar was placed as cathode (fig.6).Anodization was performed on the mini- screws at different time interval and different voltage. The specimens were washed with distilled water and ethanol and then dried. Surface porosity, thread width, and hardnesstest of all specimen were carried out.

Results: The result suggest that there is increase in surface porosities and thread width after anodization whereas the micro-hardness is decreased.

Conclusion: Micro-hardness after anodization decreases but the end value fluctuates between different voltage and time parameters. There is increase in thread width after anodization which is directly proportional to the voltage applied and time duration. Surface porosities after anodization increases but the end value fluctuates between different voltage and time parameters.

Introduction

The success of orthodontic treatment hinges on the anchorage protocol planned for a particular case. Amongst these anchorage devices, mini-screws have been increasingly used because of their ease in placement and removal, low cost and potential for absolute anchorage.

The immediate or early loading protocol used routinely in miniscrews therapy will not allow sufficient time for bone to relieve these insertion stresses by remodelling or other relaxation mechanism. Hence, modifications of the osseointegration into orthodontic mechanics was improvised based on experiences with interdisciplinary dentistry.

Titanium and its alloy have been widely used in orthodontic implants manufacturing as they present many advantages such as excellent biocompatibility, superior mechanical strength and high corrosion resistance, but the problem lies in the interfacial bond between the tissue and the implant due to its bioinert nature. Various approaches have been utilised to increase the surface roughness for an increased biocompatibility and functionality of implants and thus promote bone- tissue integration.[1-3]

While titanium oxide layer can form naturally through reacting with oxygen; however controlled oxide layer can be performed by means of chemicals; thermal (i.e. heating up to 400^0C); or electrochemical oxidation known as anodizing. The development of new surfaces can improve the overall performance of titanium implants, particularly in regard to biocompatibility, the healing time after implantation and the long- term integrity and stability of the biomaterial/body interface. Highly organized titania nanotubes are rarely synthesized on titanium implant.[4]

The electrochemical anodization of titanium alloys is considered an effective processing method applied to enhance their surface roughness and their biocompatibility. [5-7] Many studies were dedicated to, understand the role of the synthesis parameters on the

Aim and Objectives:

To evaluate and compare the surface characteristics of titanium alloy orthodontic temporary anchorage devices following anodization.

Materials and Methods:

Materials

The materials used in the study were,

1. Titanium alloy mini-screws of length 8mm, diameter 1.3 mm (anode) The mini-screws used were of JSV Orthodontics™ (fig-1)
2. Cathode (Aluminium bar-fig 2), Electrolyte -0.4% sodium bicarbonate (w/w) in 1:1(w/w) water-glycerol (fig-3,5)
3. Batteries (Hi watt)™, Alligator clips(fig-4) .
4. Distilled water and ethanol (fig-7).
5. Vision Inspection System. Company: Sipcon Measuring Systems, India.™ Model No. AVI-IMG-3D-100X Zoom, was used to detect surface porosity and threads width measurement (fig-8).
6. Micro-hardness Tester, Reichert Austria Make,™ Sr.No.363798, Load- 50 g, Reference Standard: ISO 6507 was used to detect hardness of the miniscrews (fig-9).

microstructure formation in the titanium oxide films. [8-9]

The main factors are the electrolyte type, the anodizing time, the anodizing voltage and the characteristics of the titanium implant i.e. surface composition, hydrophilicity, and morphology including microgeometry and roughness.[10-12]

The studies which were previously conducted were on titanium implants used for orthopaedic application. Too little information is available regarding the changes induced by anodization on orthodontic implants devices.

Hence it is important to investigate their effect on the surface characteristics of titanium alloy of orthodontic temporary anchorage devices (TADs).

Methodology:

The sample used in the study included 80 mini-screws of JSV Orthodontics™ (fig 1).

The screws were placed as anode in the electrolytic cell using alligator clips whereas aluminium bar was placed as cathode (fig.6).Anodization was performed on the mini-screws at different time interval and different voltage. The specimens were washed withdistilled water and ethanol and then dried. Surface porosity, thread width, and hardness test of all specimen were carried out.

Groups:

A total of 80 mini-screws were randomly divided into four groups of 20 samples each, based on anodization time and voltage. Group A (No anodization-control group 20 samples), Group B (Anodization time- 8 hrs, Voltage-25 Volts-20 samples), Group C (Anodization time-16hrs, Voltage- 40 volts- 20 samples) and Group D (Anodization time-24hrs,Voltage -60 volts 20 Samples).

To detect micro hardness screws were embedded in acrylic block. Surface porosity and thread width of all the specimen were checked by vision inspection system and surface hardness was checked by surface micro-hardness tester machine with a load of50 grams.

Inclusion Criteria:

1. Mini-screws with standardized dimensions

of length 8mm, diameter 1.3 mm.

2. Aluminium rod.
3. Freshly prepared electrolyte -0.4% sodium bicarbonate (w/w) in 1:1(w/w) water-glycerol

Exclusion Criteria:

1. Pre-used mini-screws
2. Any other (such as aluminium, vitallium, vanadium) mini-screws than titanium
3. Surface defects visible to eye such as scratches, breakage of TADs. Results

Statistical Analysis Details:

The software used was SPSS (Statistical Package for Social Sciences) version 19.

All the data were entered into Microsoft Excel 2010. Descriptive statistics were expressed as **mean ± standard deviation (SD)** for each group for micro-hardness andthread width measurement. **Frequency Distribution and percentage** were used to elaborate results of Surface porosity evaluation. Four groups were compared for micro- hardness / thread width measurement by **Analysis of variance (ANOVA)** followed by **Tukey's Post hoc Test** for pairwise comparison. For Surface porosity evaluation results were compared among groups by Independent **Kruskal Wallis Test.**

Simple/Multiple bar chart were used for graphical representation.

All the above test 'p' value was considered statistically significant when it was <0.05.

The micro-hardness in HV of non-anodized (control group) and anodized group at different time interval and different voltage is presented (**Table 1**). The mean micro- hardness of the samples were in increasing order from Group B to Group D then Group C and then Group A respectively **(Fig 12).**

The thread width in µm of non-anodized (control group) and anodized group at different time interval and different voltage is presented (**Table 4**).The mean thread width of the samples were in increasing order from Group A to Group B then Group Cand then Group D respectively **(Fig 12).**

The surface porosities of non-anodized (control group) and anodized group at different time interval and different voltage is presented (**Table 7**). The surface porosities of the samples were in increasing order from non-anodized group to anodizedgroup respectively (**Fig 14).**

The result suggest that there is increase in surface porosities and thread width after anodization whereas the micro-hardness is decreased**.**

Discussion:

A temporary anchorage device (TAD) is a device that is temporarily fixed to bone for the purpose of enhancing orthodontic anchorage either by supporting the teeth of the reactive unit or by obviating the need for the reactive unit altogether, and is subsequently removed after use.

There are various methods available for performing the surface modification of dental implants. Amongst them are bioactive coating applications, chemical applications, and abrasive blasting of the outer layer.[13]

Anodization procedure of titanium includes alkaline cleaning, acid activation, and electrolyte anodizing. When a constant voltage or current is applied between the anode and cathode, electrode reactions (oxidation and reduction) in combination with field- driven ion diffusion lead to the formation of an oxide layer on the anode surface.

Sul et al[14] in their original research article described anodization as a process used to alter the topography and composition of the surface by increasing the thickness of the titanium oxide layer, roughness and an enlarged surface area. This moderately roughsurface was reported to enhance osteoblast cell adhesion to titanium implants.

Gaetano Marenzi et al[15] in their original research article, stated that despite the numerous advancements in the field of anodization research gaps exists within the lack of fabrication optimization, performed on a substrate of conventional implant micro-topography and inadequate mechanical stability. Dental implants are not flat surfaces but 3D objects with curved surfaces, which increase the chance of anodic film cracks and delamination, owing to greater internal stress, volume expansion and the presence of so-

called "weak spots" These conditions compromise implant stability and lead to toxicity and complete implant failure.

Pilling and Bedworth[16] in their original research article proposed that the ratio of the specific volumes of the oxide to its parent metal is a predictor of the ability of the oxide to protect the substrate from corrosion. Oxides with Pilling–Bedworth ratios slightly greater than 1.0 were thought to develop protective residual compressive stresses. Oxide strength may be dependent upon the potential at which it was formed and scratch tested.

Similarly in the present study, decrease in the micro-hardness of the sample were observed which can occur due to increase in the chance of anodic film cracks i.e. weakspot , owing to greater internal stress and volume expansion.

An in vitro study by **Young-Taeg Sul, Carina B. Johansson, Yongsoo Jeong, Tomas Albrektsson**[3] reported that the galvanostatic anodic oxide films demonstrate the interference colours of the titanium oxide. These interference colours can be utilized for a quick identification purposes of oxide thickness which linearly increases with increased applied voltage below breakdown voltage.

The study by **Jay R Goldberg, Jeremy L Gillbert**[2] confirmed that oxide film thickness increases with electric potential.

L. Le Guehennec, A. Soueidan, P. Layrolle, Y. Amouriq[17] in their original research article observed that the result of the anodization is to thicken the oxide layer to more than 1000 nm on titanium.

Chang Yao and Thomas J. Webster[8] in their original research article reported that the thickness of the tubular-structured oxide can be as small as a few hundred nanometers to a few microns by controlling pH and electrolyte type and concentration.

D. V. Portan, K. Papaefthymiou, E. Arvanita, G. Jiga, G. C. Papanicolaou[18] in their original research article observed that the type of electrolyte used in the experiment influences the structure of the nanotubes, sketched due to the existence of different concentrations of ions. The monolayer of nanotubes synthesized in organic electrolytes e.g. glycerol, shows a more uniform and regular shape.

In the study by **Diana Portan et al**[4] it was experimentally observed that a longer anodization time shall be associated with thicker samples while the increased electric potential, leads to more intense processes, has to be applied in the case of porous titanium.

R.I.M. Asri et al[11] in their original research article stated that Anodizing is a well- known method for the fabrication of different types of protective oxide films on metals.

In the present study we observed that the thread width of the samples increased (thickening the oxide layer) after anodization that can be due to the electric potential and anodization time.

Chang Yao and Thomas J. Webster[8] in their original research article observed that the typical morphology of the titania layer resulting from ASD is a rough, porous texture with cracks present on it. The dimensions of the pores varied from a few hundred nanometers to a few micrometers depending on the processing parameters utilized and are not uniform within the same anodized surface.

An in vitro study by **Claudiu Constantin Manole and Cristian Pirvu**[6] reported that with increase in voltage, the ordered structures shift from nanotubular aspect toward a porous distribution on the surface.

D. V. Portan, K. Papaefthymiou, E. Arvanita, G. Jiga, G. C. Papanicolaou[18] in their original research article stated that at low voltage, small pits which develop to pores are created on the TiO_2 film. Pore size increases fast at higher voltage values, due to rapid localized dissolution of the TiO_2.

Ling Gao et al[5] in their original research article stated that the micro/nanostructuralporous surface has a broad pore size distribution, from 100 nm to 60 µm. This porous structure could anchor osteocytes and improve osseointegration, which provides spacefor new bone tissue ingrowth

Ivanoff et al.[19] in their research article demonstrated that a faster integration of the implant in the bone could be achieved as a result

of ossteoconductive properties of the anodised design.

A ten-year follow-up of immediately loaded implants with porous anodised surfaces reported a cumulative 65.26% success rate and 97.96% survival rate.

L. Le Guehennec, A. Soueidan, P. Layrolle , Y. Amouriq[17] in their original research article stated that when strong acids are used in an electrolyte solution, the oxide layer will be dissolved along current convection lines and thickened in other regions. The dissolution of the oxide layer along the current convection lines creates micro or nano-pores on the titanium surface.

R.I.M. Asri et al[11] in their original research article observed that titanium surfaces altered through anodization method at high voltages influence the crystallization of the oxide surface and thereby provide preferred porosity and roughness

Gaetano Marenzi et al[15] in their original research article observed that anodizationin acid electrolyte provides a conformal coating with pores also formed on curved surfaces of commercial grade Ti, even in the absence of cathodic pre-treatment step, and is thus a viable inexpensive approach for the nanopatterning of dental implant surfaces.

In the present study we used a basic electrolyte ($NaHCo_3$) and still observed that the surface porosity of the samples increased after anodization it can be due to the increasein voltage and increase in the anodization time.

In a randomised clinical trial by **Rocci A, Martignoni M, Gottlow J**[20] stated that anodised implant survival rates were reported to be higher than machined implants (95.5% and 85.5% respectively).

Anodized surfaces result in a strong reinforcement of the bone response with higher values for biomechanical and histo-morphometric tests in comparison to machined surfaces. A higher clinical success rate was observed for the anodized titanium implants in comparison with turned titanium surfaces of similar shapes.[21-25]

In the present study the decrease in the micro-hardness of the TADs may be due to delamination and increase in the chance of anodic film cracks i.e. weak spot, owing to greater internal stress and volume expansion due to increased pores formation depending upon electric potential. Whereas the increase in the thread width due to oxide layer synthesis and increased surface porosity improves mechanical retention due to increase in surface area which provides space for new bone tissue ingrowth i.e. improved survival rate of the TADs.

Limitation of the study:

The present study model is simple anodization process which is feasible in day to day scenario but the end values of some parameters fluctuates between different voltage and time.

There is still controversy about the nature of breakdown, the mechanism of ionic transfer through the growing film, the rate of growth in different electrolytes, and the distribution of the electric field across the oxide.

However different parameters i.e. different electrolytes, different electric potential, change in time parameter, may have different effect on the characteristics of mini- screws therefore further studies can be carried out.

Conclusion:

The following conclusions were drawn from the present study:

1. Micro-hardness after anodization decreases but the end value fluctuates between different voltage and time parameters.
2. There is increase in thread width after anodization which is directly proportional to the voltage applied and time duration.
3. Surface porosities after anodization increases but the end value fluctuates between different voltage and time parameters.

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List Of Figures:

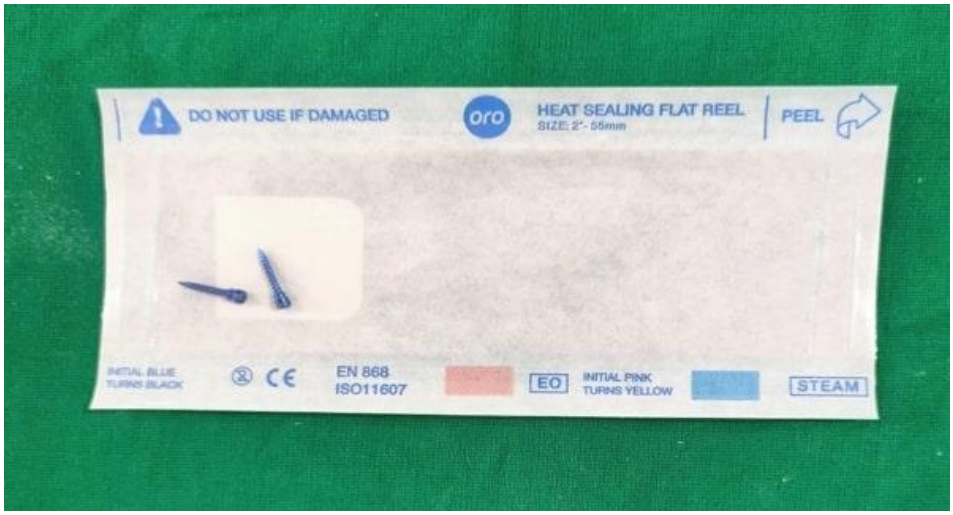


Fig 1

Fig 2

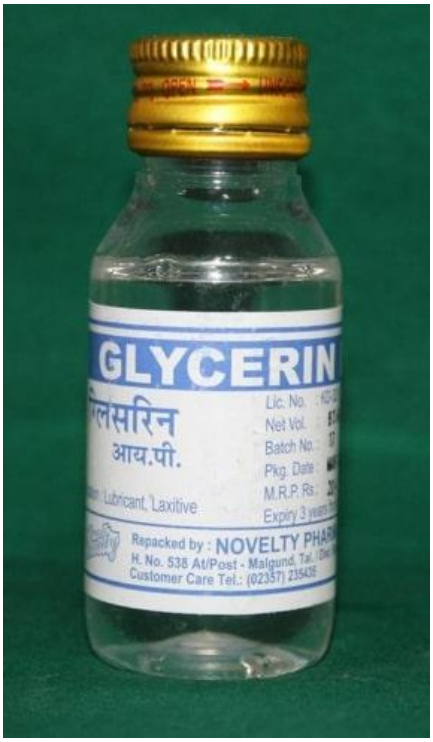


Fig 3

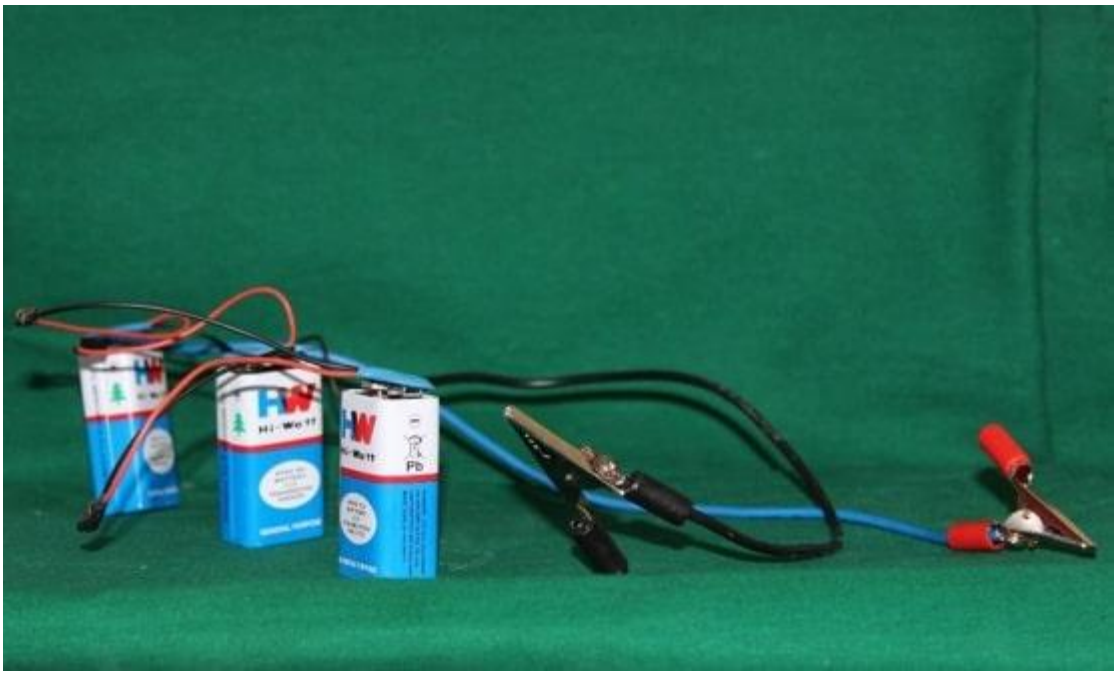


Fig 4

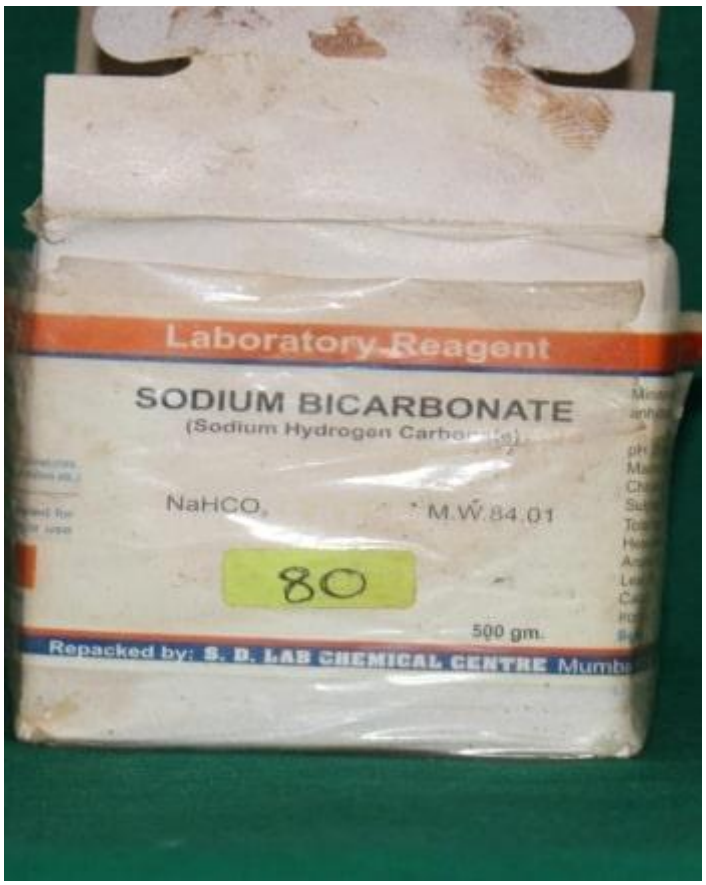

Laboratory Reagent
SODIUM BICARBONATE
NaHCO3
M.W.84.01
80
500 gm.
Repacked by: S. D. LAB CHEMICAL CENTRE

Fig 5

Fig 6


Ethanol AR 99.9%
BATCH NO: 20170425
Danger
500ml
Highly flammable liquid and vapour
Causes eye irritation
May cause respiratory irritation
May cause damage to organs
For laboratory Use only
Jiangsu Huasi International
Trade Co.Ltd Made In China

Fig 7

Fig 8

Fig 9

Fig 10

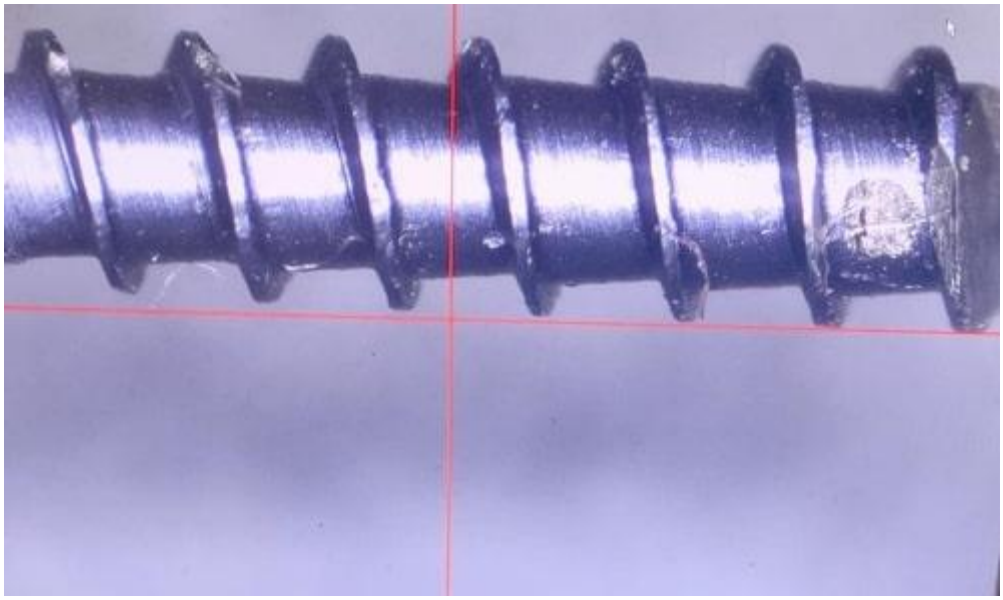
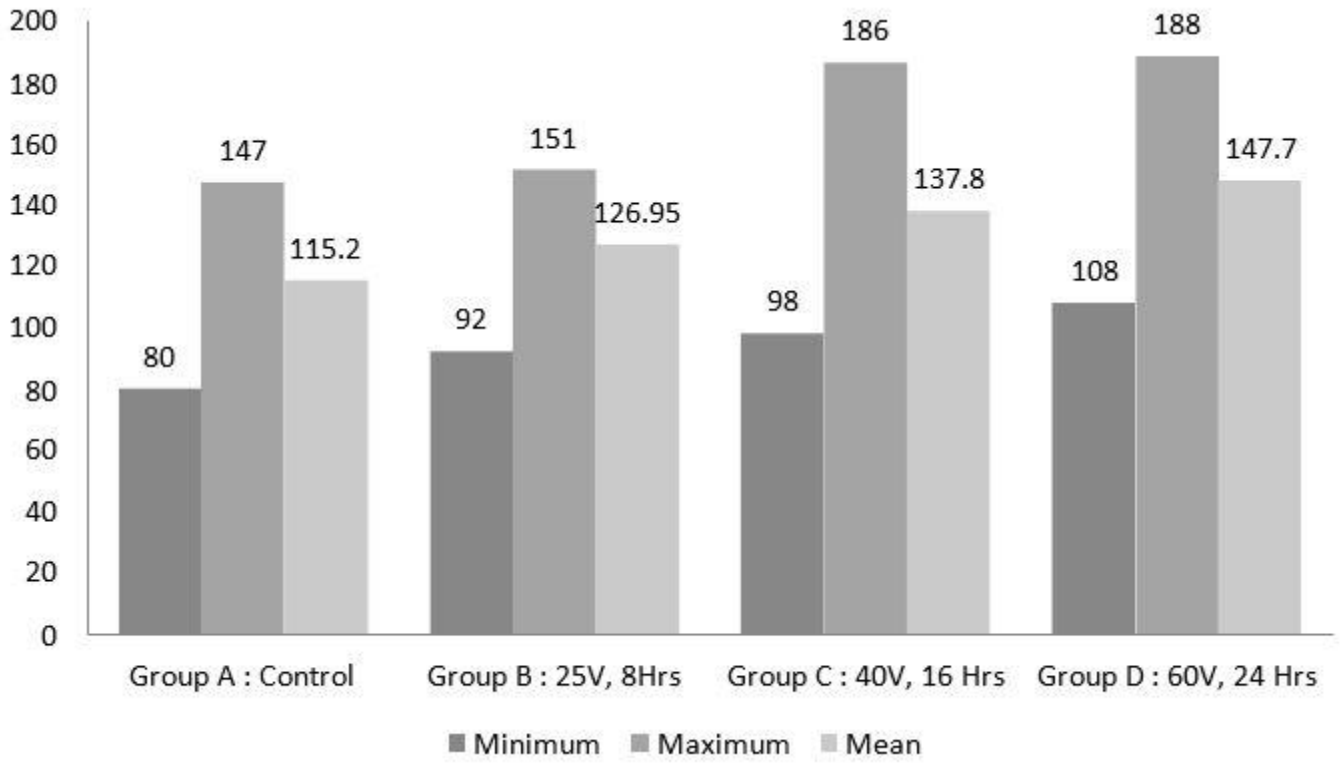


Fig 11


450
400
350
300
250
200
150
100
50
0
280
404
255
302
198
346
212
330
Group A : Control
Group B:25V, 8Hrs
Group C : 40V, 16 Hrs
Group D : 60V, 24 Hrs
Minimum
Maximum
Mean

Fig 12


200
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Group A : Control
Group B : 25V, 8Hrs
Group C : 40V, 16 Hrs
Group D : 60V, 24 Hrs
Minimum
Maximum
Mean

Fig 13

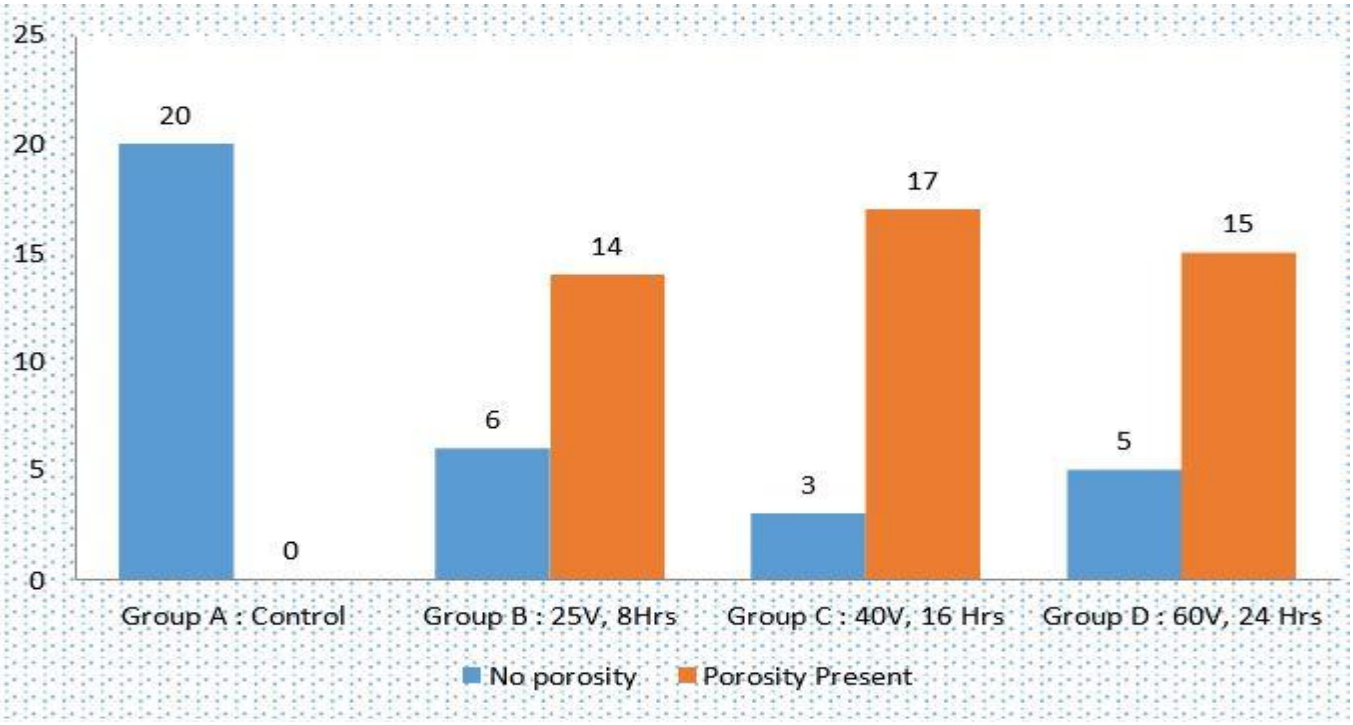

Fig 14

Table 1 Descriptive Statistics for Micro-hardness among four group

Descriptive Statistics					
Group	N	Minimum	Maximum	Mean	Std. Deviation
Group A : Control	20	280	404	341.20	52.543
Group B : 25V, 8Hrs	20	255	302	277.80	13.629
Group C : 40V, 16 Hrs	20	198	346	301.60	40.741
Group D : 60V, 24 Hrs	20	212	330	278.50	28.580

Table 2 Comparison of Micro-hardness among four groups by Analysis of variance

ANOVA					
Micro-hardness					
	Sum of Squares	Df	Mean Square	F	Sig. p Value
Between Groups	53097.750	3	17699.250	13.055	<0.001*
Within Groups	103040.200	76	1355.792		
Total	156137.950	79			

***Statistically Significant**

Table 3. Group-wise one to one Comparison of Micro-hardness among fourgroups by Tukey's post hoc test.

Multiple Comparisons						
Dependent Variable: Micro-hardness **Tukey HSD**						
(I) Groups	(J) Groups	Mean Difference (I-J)	Std. Error	Sig. p Value	95% Confidence Interval	
					Lower Bound	Upper Bound
Group A : Control	Group B : 25V, 8Hrs	63.400*	11.644	<0.001*	32.81	93.99
Group A : Control	Group C : 40V, 16 Hrs	39.600*	11.644	0.006*	9.01	70.19
Group A : Control	Group D : 60V, 24 Hrs	62.700*	11.644	<0.001*	32.11	93.29
Group B : 25V, 8Hrs	Group C : 60V, 24 Hrs	23.100	11.644	0.203	-7.49	53.69
Group B : 25V, 8Hrs	Group D : 60V, 24 Hrs	23.100	11.644	0.203	-7.49	53.69
Group C : 40V, 16 Hrs	Group D : 60V, 24 Hrs	23.100	11.644	0.203	-7.49	53.69
***. The mean difference is significant at the 0.05 level.**						

***Statistically Significant**

Table 4 Descriptive Statistics for Thread Width Measurement among four groups

Descriptive Statistics					
Group	N	Minimum	Maximum	Mean	Std. Deviation
Group A : Control	20	80	147	115.20	20.201
Group B : 25V, 8Hrs	20	92	151	126.95	17.276
Group C : 40V, 16 Hrs	20	98	186	137.80	22.950
Group D : 60V, 24 Hrs	20	108	188	147.70	25.058

Table 5 Comparison of Thread Width Measurement among Four groups byAnalysis of variance (ANOVA)

ANOVA					
Thread Width Measurement					
	Sum of Squares	df	Mean Square	F	Sig.p Value
Between Groups	11756.837	3	3918.946	8.423	<0.001*
Within Groups	35361.550	76	465.284		
Total	47118.388	79			

***Statistically Significant**

Table 6. Group-wise one to one Comparison of Thread Width Measurementamong Four groups by Tukey's post hoc test.

Multiple Comparisons						
Dependent Variable: Thread Width Measurement Tukey HSD						
(I) Groups	(J) Groups	Mean Difference (I-J)	Std. Error	Sig. p Value	95% Confidence Interval	
					Lower Bound	Upper Bound
Group A : Control	Group B : 25V, 8Hrs	-11.750	6.821	0.319	-29.67	6.17
Group A : Control	Group C : 40V, 16 Hrs	-22.600*	6.821	0.008*	-40.52	-4.68
Group A : Control	Group D : 60V, 24 Hrs	-32.500*	6.821	<0.001*	-50.42	-14.58
Group B : 25V, 8Hrs	Group C : 60V, 24 Hrs	-10.850	6.821	0.390	-28.77	7.07
Group B : 25V, 8Hrs	Group D : 60V, 24 Hrs	-20.750*	6.821	0.017*	-38.67	-2.83
Group C : 40V, 16 Hrs	Group D : 60V, 24 Hrs	32.500*	6.821	<0.001*	14.58	50.42
***. The mean difference is significant at the 0.05 level.**						

***Statistically Significant**

Table 7 Frequency Distribution for surface porosity among four groups

OBSERVATION					
Groups		Frequency	Percent	Valid Percent	Cumulative Percent
Group A : Control	NO POROSITY	20	100.0	100.0	100.0
Group B : 25V, 8Hrs	NO POROSITY	6	30.0	30.0	30.0
	POROSITY PRESENT	14	70.0	70.0	100.0
	Total	20	100.0	100.0	
Group C : 40V, 16 Hrs	NO POROSITY	3	15.0	15.0	15.0
	POROSITY PRESENT	17	85.0	85.0	100.0
	Total	20	100.0	100.0	
Group D : 60V, 24 Hrs	NO POROSITY	5	25.0	25.0	25.0
	POROSITY PRESENT	15	75.0	75.0	100.0
	Total	20	100.0	100.0	

Table 8 Comparison of Distribution for surface porosity four groups by KruskalWallis's Test.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Observation is the same across categories of Groups.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

	Null Hypothesis	Test	p Value	Decision
1	The distribution of Observation is the same across categories of groups	Independent samples Kruskal Wallis Test	<0.001*	Reject the null hypothesis

*Statistically Significant

Table 9 Paired wise Comparison of Distribution for surface porosity among fourgroups by Kruskal Wallis's Test.

Group(i)	Group (j)	p Value
Group A : Control	Group B : 25V, 8Hrs	0.009*
Group A : Control	Group C : 40V, 16 Hrs	<0.001*
Group A : Control	Group D : 60V, 24 Hrs	<0.001*
Group B : 25V, 8Hrs	Group C : 40V, 16 Hrs	0.732
Group B : 25V, 8Hrs	Group D : 60V, 24 Hrs	0.231
Group C : 40V, 16 Hrs	Group D : 60V, 24 Hrs	1.000

***Statistically Significant**