Evaluation of %Weight Loss and Surface Roughness of Duplex Coated Ti6al4v Alloy using Taguchi Optimisation Technique

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ABSTRACT

The main objective of this work is to evaluate the %Weight loss and surface roughness of duplex coated Ti6Al4V alloy using Taguchi Optimisation Technique. In the present work, Taguchi Design is considered with four process parameters: applied load, sliding speed, sliding distance and track diameter each to be varied in four different levels. Data related to %Weight loss and surface roughness have been measured for each experimental run. The variation of output responses with process parameters were mathematically modelled by using Taguchi Optimisation Technique. Response is predicted and Signal to Noise ratio was applied to %weight loss and surface roughness. Results showed that the predicted and experimental values are good in agreement. The contribution of each process parameter is also determined by using ANOVA.

Keywords — *%Weight Loss, Surface Roughness, Design of Experiments, Taguchi method*.

I. INTRODUCTION

1.1 Introduction to Titanium and its alloys.

Titanium is a newcomer among the metals that have gained widespread industrial importance. Commercially pure titanium has acceptable mechanical properties and has been used for orthopedic and dental implants. Titanium is classified as a "Transition Metal" which is located in Groups 3 - 12 of the Periodic Table. It is ductile, malleable, and able to conduct electricity and heat. Titanium has low density and high strength, good corrosion and erosion resistance to different media, good oxidation resistance and moderate strength at high temperatures. Titanium alloys [1] are metals that contain a mixture of titanium and other chemical elements (such as aluminium, vanadium). For most applications titanium is alloyed with small amounts of aluminium and vanadium, typically 6% and 4% respectively, by weight. Such alloys have very high tensile strength and toughness (even at extreme temperatures). Titanium and its alloys find application in aerospace, the chemical and power industries, transportation, armament, and sports. **Grade 5**, also known as Ti6Al4V, Ti-6Al-4V or Ti 6-4, is the most commonly used alloy. It has a chemical composition of 6% aluminium, 4% vanadium, 0.25% iron, 0.2% oxygen, and the remainder titanium. It is significantly stronger than commercially pure titanium while having the same stiffness and thermal properties (excluding thermal conductivity, which is about 60% lower in Grade 5 Ti than in CP Ti). Among its many advantages, it is heat treatable. This grade is an excellent combination of strength, corrosion resistance, weld and fabric ability [6]. This alpha-beta alloy is the workhorse alloy of the titanium industry.

1.2 Thermal Spray Coatings.

Thermal spraying is one of the most versatile hard facing techniques available for the application of coating materials used to protect components from abrasive wear, adhesive wear, erosive wear or surface fatigue and corrosion (such as that caused by oxidation or seawater). The coatings may also increase heat resistance, when a material with a low thermal conductivity is deposited onto a base material. In thermal spraying the initial coating material (materials in the form of rod, wire, or powder) is heated, generally to a molten state and projected onto a receiving surface, known as a substrate. A variety of engineering problems have been solved using thermal spraying applications and as research continues the application of this coating technique may be used in engineering areas otherwise not considered. The use of thermal spraying ranges across many manufacturing processes such as in an automotive, chemical plants, turbine blades, aeronautical industry and space exploration industry. Thermal sprayed coatings [2] are used in a wide range of other applications such as the gas turbine, petroleum, chemical, paper /pulp, automotive and manufacturing industries. Metals, carbides and cermets are the most widely used coating materials. Within the thermal spray technique are various types of processes, such as High Velocity Oxy-Fuel (HVOF) process and detonation spray (DS) used in the present work.

Thermal spray processes, especially high velocity oxygen fuel (HVOF) and detonation spray(DS) are widely used coating techniques in many gas and oil industrial applications to protect materials from various degradation processes such as wear, erosion, high temperature and corrosive atmosphere. Metal matrix composite (MMC) coatings, in which a mixture of hard particles and metallic binder materials are normally applied on metal substrates by HVOF spraying, provide advantages to the surface mechanical properties especially wear resistance. A typical example of such coatings is tungsten carbide (WC) particles with metallic binders of Co, Ni or Co–Cr which has been applied extensively in heavy-loaded conditions, due to its excellent wear resistance.

1.3 Wire Electrical Discharge Machining.

Wire electrical discharge machining (EDM) is a non-traditional machining process that uses electricity to cut any conductive material precisely and accurately with a thin, electrically charged copper or brass wire as an electrode. During the wire EDM process [8], the wire carries one side of an electrical charge and the work piece carries the other side of the charge. When the wire gets close to the part, the attraction of electrical charges creates a controlled spark, melting and vaporizing microscopic particles of material. The spark also removes a miniscule chunk of the wire, so after the wire travels through the work piece one time, the machine discards the used wire and automatically advances new wire. The process takes place quickly and produces thousands of sparks per second but the wire never touches the work piece. The spark erosion occurs along the entire length of the wire adjacent to the work piece, so the result is a part with an excellent surface finish and no burrs regardless of how large or small the cut. Wire EDM machines use a dielectric solution of deionized water to continuously cool and flush the machining area while EDM is taking place. In many cases the entire part is submerged in the dielectric fluid, while high-pressure upper and lower flushing nozzles clear out microscopic debris from the surrounding area of the wire during the cutting process. The fluid also acts as a non-conductive barrier, preventing the formation of electrically conductive channels in the machining area. When the wire gets close to the part, the intensity of the electric field overcomes the barrier and dielectric breakdown occurs, allowing current to flow between the wire and the work piece, resulting in an electrical spark.

1.4 Taguchi Method.

Taguchi's approach was built on traditional concepts of design of experiments (DOE), such as full factorial, fractional factorial designs and orthogonal arrays, based on some new DOE techniques such as signal-to-noise ratios, robust designs, and parameter and tolerance designs. Design of experiments is a power full statistical technique introduced by RA. Fisher in England in the 19205 to study the effect of multiple variables simultaneously, [Phillips, 1989 (134)]. Such techniques are useful for the effective and efficient collection of data for a number of purposes. Taguchi method is a power full tool which can upgrade/improve the performance of the product, process, design and system with a significant slash in experimental time and cost [7].

A crucial component of quality is a product's ability to perform its tasks under a variety of conditions. Furthermore, the Operating environmental conditions are usually beyond the control of the product designers. Therefore the robust designs are essential. Robust designs are based on the use of DOE techniques for finding product / part parameter settings, which enable the products to be flexible to changes and variations in working environments.

The influence of noise on the performance characteristics can be found using the S/N ratio. Where S is the standard deviation of the performance parameters for each inner array experiment and N is the mean of total number of experiment in the outer orthogonal array. This ratio indicates the functional variation due to noise. Using this result, it is possible to predict which control parameter settings will make the process insensitive to noise. Taguchi method [9] focuses on Robust Design through use of Signal-to-Noise Ratio and Orthogonal Arrays.

II. LITERATURE REVIEW

Ming Mu *et al.* [1] demonstrated that the graphite-containing oxide composite coating by plasma electrolytic oxidation registered much lower friction coefficient and wear rate than the uncoated Ti6Al4V alloy and the oxide coating without graphite under dry sliding condition, exhibiting excellent self-lubricating property. Surface hardening of Ti6Al4V is achieved by Triode Plasma Oxidation (TPO) and the resultant surface generally consists of a top oxide layer with an oxygen diffusion zone lying immediately underneath it.

M. Magnani *et al.* [2] fabricated WC-Co coatings on an AA 7050 aluminium alloy using high velocity oxygen fuel (HVOF) technology. The friction and abrasive wear resistance of the coatings were studied using Rubber Wheel and Ball on Disk tests. The electrochemical studies were conducted using open-circuit potential (EOC) measurements and electrochemical impedance spectroscopy (EIS). Differences among coated samples were mainly related to the variation of the thermal spray parameters used during the spray process.

Osman Nuri Celik *et al.* [3] conducted wear tests under dry sliding conditions using a linear ball-on-disc geometry. The microhardness and wear resistances of all of the composite layers produced by the PTA process were enhanced relative to those of the Ti6Al4V substrate. The homogeneity and volume fractions of the carbide phases in the composite layers were responsible for the improvement in the wear resistance of the alloy.

Martini *et al.* [4] investigated the tribological performance of hydrogenated amorphous carbon (a-C: H) coatings, PA-CVD deposited on the Ti6Al4V alloy. The dry sliding friction and wear behaviour of the coated alloy was studied by a slider-on-cylinder tribometer, at room temperature and in laboratory air, under the same sliding speed (0.3 m/s) and distance (1000 m), in the load range 5–90 N. The dry sliding behaviour of the coated systems was studied by a flat-on-cylinder tribometer (load range 30–60N).A critical load, corresponding to the end of coating life, was identified for each coated system. The highest critical loads were observed for CrN- and WC/C-coated Ti-6Al-4V.However, only WC/C also led to a significant decrease of the coefficient of friction. The good performance of WC/C-coated Ti-6Al-4V was ascribed to both the high H/E ratio of the coating and to the best match of elastic modulus with the substrate.

Bemporad *et al.* [5] deal with design, production and experimental characterisation of a duplex coating for Ti–6Al–4V components, consisting of a thick WC–Co interlayer deposited by High Velocity Oxygen Fuel (HVOF), followed by a Ti/TiN multilayer (two layer pairs, including the Ti bond layer) deposited by Cathodic Arc Evaporation (CAE) PVD Authors reported that the use of a CAE-PVD multilayer Ti/TiN top layer, whose thicknesses and Ti distribution were suggested by finite element modelling optimisation, leads to a significant increase (45%) in adhesion of PVD coating to the HVOF layer and load bearing capacity of the coated system, compared to monolayered TiN, without reduction in superficial hardness and load bearing capacity.

Yildiz *et al.* [6] identified about wear and corrosion behaviour of various surface treated medical grade titanium alloy in bio-simulated environment. Ti6Al4V alloy has been widely used as a suitable material for surgical implants such as artificial hip joints. Although this alloy is biocompatible, its wear resistance is inadequate. Therefore, three different surface treatments which were plasma nitriding, TiAlN thin film deposition by closed field unbalanced magnetron sputtering (CFUBMS) and Al_2O_3 coating using plasma spray method were applied to the alloy to improve the tribological and electrochemical properties. To simulate human body environment, wear experiments were performed by using pin-on-disc tribotester in Ringer's solution at 37 °C. Moreover, potentiodynamic corrosion tests were carried out in Ringer's solution. It was observed that each three surface treatments improved wear and corrosion resistance of Ti6Al4V alloy

III. EXPERIMENTATION

3.1Base Material Preparation.

Ti6Al4V specimen of Ø25 X 36 mm size is taken as shown in Fig-3.1. The substrate surfaces were grit blasted with alumina grits using grit blasting equipment, followed by an ultrasonic cleaning in acetone to attain enough surface roughness for the best adhesion between coating and substrate.

In the present work, thermal spray techniques were employed to deposit duplex coatings on to Ti6Al4V alloy. High velocity oxy-fuel (HVOF) process [5] belong to the thermal spray coating technologies group and are capable of producing coatings with higher hardness, superior bond strength and less decarburization during spraying than many of the other thermal spraying methods. Detonation spray (DS) is another thermal barrier coating technology expelling the melting or semi-melting state powder heated by the combustion of fuel and oxygen to the surface of working piece at a high speed, which has been extensively used in many fields, such as aviation, space flight, petroleum, metallurgy and other chemical and machinery industries. This technique gives an extremely good adhesive strength, low porosity and coating surfaces with compressive residual stresses.High velocity oxy-fuel technique was used to deposit NiCrAlY interlayer coatings onto the base material with coating thickness 200 µm and detonation spray technique was used to deposit WC-Co top coat with coating thickness 450 µm. The coated specimen is shown in Fig-3.2.

Fig-3.1

Fig-3.2

Using wire EDM the specimen is cut into no. of specimens of size Ø3 X 36 mm by varying the factor considered in DOE. 16 specimens are used for the present work. Drawing for Wire EDM is shown in Fig-3.3 and specimens obtained after machining are shown in Fig-3.4.

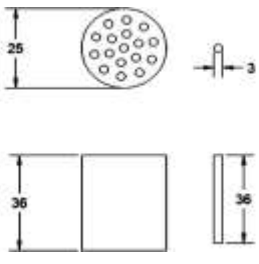

Fig-3.3 Drawing for wire EDM

Fig-3.4 Specimens obtained from Wire EDM

3.2 Design of Experiments.

Design of Experiments is an analytical method commonly used to statistically signify the relationship between input parameters to output responses. DOE has wide applications especially in the field of engineering for the purpose of process development, optimization and validation tests. DOE is essentially an experimental based modelling and is a designed experimental approach which is far superior to unplanned approach whereby a systematic way will be used to plan the experiment, collect the data and analyse the data. In the present work a mathematical model has been developed by Taguchi Approach. Optimization and Desirability functions obtained helps to optimize characteristics considered for Minimum %Weight Loss and Surface Roughness. Process Parameters and their Levels for conducting wear test by using pin-on-disc apparatus are load, sliding speed, sliding distance and track diameter shown in Table-3.1 which are considered based on the literature [3].

3.2 .1 Process Parameters and their Levels for conducting Experiments:

Table 3.1: Process variables and their limits

Parameters	**Levels**			
	1	**2**	**3**	**4**
Load(N)-A	5	10	15	20
Sliding speed(rpm)-B	100	200	300	400
Sliding distance(m)-C	100	200	300	400
Track diameter(mm)-D	50	60	70	80

3.3 Minitab Software

Minitab is a statistics package. It was developed at the Pennsylvania State University by researchers Barbara F. Ryan, Thomas A. Ryan, Jr., and Brian L. Joiner in 1972. Minitab began as a light version of MNITAB, a statistical analysis program by NIST. Minitab is distributed by Minitab Inc, a privately owned company headquartered in State College. Pennsylvania, with subsidiaries in Coventry, England, Paris, France and Sydney, Australia. Minitab is often used in conjunction with the implementation of Six sigma, CMMI and other statistics-based process improvement methods.

3.4 Orthogonal Array.

A large number of experiments have to be carried out when the number of the process parameter increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. From the preliminary experimental “guns, three levels of the cutting parameters have been selected. In this study, Taguchi experimental design L16 orthogonal array is chosen for 16 experiments. It considers four process parameters to be varied in four discrete levels. The experimental design has been shown in Table 3.2 (all factors are in coded form).

Table 3.2: DOE in Coded form

Expt.No	**A (N)**	**B (rpm)**	**C (m)**	**D (mm)**
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

3.5 % Weight Loss (%Wt loss).

The %Wt loss of the specimens is calculated by using the formula

$$\%Wt\ loss = (W_1 - W_2/W_1)100 \quad mm^3/min$$

Where, W_1 = Weights of the specimens before conducting wear test.

W_2= Weights of the specimens after conducting wear test.

Weight of the specimens before and after the experiment was taken with help of sensortron balance with an accuracy of ±0.1mg as shown in Fig-3.5.

Fig 3.5: Sensortron

3.6 Surface Roughness(S/F R).

Surface roughness of the specimens is measured using Surface Roughness Tester which directly shows the reading when placed on the metal surface. It consists of a stylus which moves on to the surface of the metal. This directly shows the surface roughness value in terms of any desired unit. Fig-3.6 shows the surface roughness tester.

Fig 3.6 Surface Roughness Tester

IV. RESUTS AND DISCUSSIONS

4.1 Process Responses of %Wt loss and Surface Roughness.

Wear test was conducted for a total 16 no. of experiments on a pin on disc apparatus [4]. After wear testing the %Wt loss and Surface Roughness of Ti6Al4V are analysed to get an optimized solution. Table 4.1 shows DOE in decoded form i.e. design layout for conducting experiment on titanium alloy as per Taguchi design. Table 4.2 shows process response of Ti6Al4V on %Wt loss and S/F Roughness.

Table 4.1: DOE in Decoded form

Expt. No	A (N)	B (rpm)	C (m)	D (mm)
1	5	100	100	50
2	5	200	200	60
3	5	300	300	70
4	5	400	400	80
5	10	100	200	70
6	10	200	100	80
7	10	300	400	50
8	10	400	300	60
9	15	100	300	80
10	15	200	400	70
11	15	300	100	60
12	15	400	200	50
13	20	100	400	60
14	20	200	300	50
15	20	300	200	80
16	20	400	100	70

Table 4.2: Process Responses of %Wt loss and S/F Roughness

S.No	A	B	C	D	%Wt Loss	S/F R
1	5	100	100	50	1.097	2.905
2	5	200	200	60	0.906	3.38
3	5	300	300	70	1.184	4.07
4	5	400	400	80	1.235	3.255
5	10	100	200	70	1.104	3.845
6	10	200	100	80	0.965	3.9
7	10	300	400	50	0.907	3.05
8	10	400	300	60	1.082	4.045
9	15	100	300	80	1.055	3.096
10	15	200	400	70	1.028	3.975
11	15	300	100	60	0.929	2.925
12	15	400	200	50	1.124	3.95
13	20	100	400	60	0.89	3.567
14	20	200	300	50	1.978	3.72
15	20	300	200	80	0.964	3.515
16	20	400	100	70	1.224	3.835

Table 4.3: S/N ratios for %Wt loss and Surface Roughness of Ti6Al4V

Expt. No	%Wt loss	S/N Ratios	S/F R	S/N Ratios
1	1.097	-0.80413	**2.905**	**-9.2629**
2	0.906	0.85744	3.380	-10.5783
3	1.184	-1.46703	4.070	-12.1919
4	1.235	-1.83334	3.255	-10.2510
5	1.104	-0.85938	3.845	-11.6979
6	0.965	0.30945	3.900	-11.8213
7	0.907	0.84785	3.050	-9.6860
8	1.082	-0.68455	4.045	-12.1384
9	1.055	-0.46505	3.096	-9.8160
10	1.028	-0.23986	3.975	-11.9867
11	0.929	0.63969	2.925	-9.3225
12	1.124	-1.01533	3.950	-11.9319
13	**0.890**	**1.01220**	3.567	-11.0461
14	1.978	-5.92453	3.720	-11.4109
15	0.964	0.31846	3.515	-10.9185
16	1.224	-1.75563	3.835	-11.6753

4.2. Taguchi Design in Minitab

In this paper, Analysis of the experimented values was carried out in MINITAB v17 for optimizing the process parameters. The Signal to Noise (S/N) ratios and Response of Means for output parameters were computed according to Taguchi technique using Minitab. The Analysis of Variance (ANOVA) is also computed for S/N ratios using Minitab. T able 4.3 Shows S/N rations for %Wt loss, and Surface Roughness of Ti6Al4V.

4.3. S/N Ratio Analysis for %Wt Loss.

Higher values of the (S/N) signal-to-noise ratio identify control factor settings that minimize the effects of the noise factors.

The signal-to-noise ratio measures how the response varies relative to the nominal or target value under different noise conditions. For static designs, Minitab offers four signal-to-noise ratios. The goal of this experiment is to have low %Wt loss, so smaller the better S/N ratios are selected in this case.

$$S/N = -10 * \log (\Sigma (Y^2)/n))$$

The graph shown in Fig 4.1, gives the effect of each parameter on the response %Wt loss. First, the S/N ratio mean is calculated for each level of each parameter and then a plot is generated as show below to show at which level of each parameter the mean of S/N ration is higher. The level at which level of each parameter the mean of S/N ration is higher. The level at which the S/N ratio is higher will give the higher signal for the required response, %Wt loss in this case. That particular level of each parameter is taken as the optimal parameter for %Wt loss, as per Taguchi optimization.

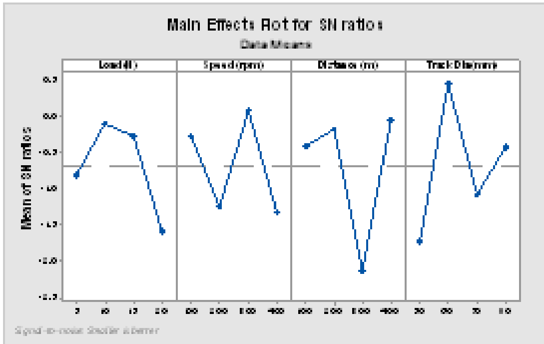

Fig 4.1: Effect of control factors on %Wt loss of Ti6Al4V.

Table 4.4 shows the Response Table for S/N Ratios of %Wt loss. Optimal parameters from the below table by Taguchi design for %Wt loss are load=20N, sliding speed=100 rpm, sliding distance=400 m, track diameter=60 mm

Table 4.4: Response Table for S/N Ratios (smaller is the better)

Level	Load(N)	Sliding Speed (rpm)	Sliding Distance (m)	Track Diameter (mm)
1	-0.81177	-0.27907	-0.40266	-1.72903
2	-0.09665	-1.24937	-0.17470	0.45619
3	-0.27014	0.08474	-2.13529	-1.08048
4	-1.58737	-1.32221	-0.05329	-0.41762
Delta	1.49072	1.40695	2.08200	2.18023
Rank	3	4	2	1

4.3.1 Predicted %Wt loss:

Predicted S/N ratio = Y + (Load4-Y)
+ (Sliding Speed1–Y)
+ (Sliding Distance4–Y)
+ (TrackDiameter2-Y)

Where Y= Average of S/N ratio Values for %Wt loss i.e.

Y= (SN+SN2+SN3+SN4+SN5+SN6+...SN16)/16

Y= -0.69148.

Distance, Speed, Load, Track diameter values are taken from the response Table- 4.4

Predicted S/N ratio = -0.69148
+ (-1.58737-(-0.69148))
+ (-0.27907-(-0.69148))
+ (-0.05329-(-0.69148))
+ (0.45619-(-0.69148))

Predicted S/N ratio = 0.6109 (smaller the better)

For Smaller-the-Better

$S/N \text{ ratio} = -10 \log (MSD)^2$

$0.6109 = -10 \log (\%Wt \text{ loss})^2$

%Wt loss = 0.932(Predicted value)

4.3.2 Analysis of Variance for %Wt loss:

Analysis of variance (ANOVA) is used in order to find out the Percentage of contribution of each process parameter on %Wt loss of Ti6Al4V.

Table 4.5: Analysis of Variance for %Wt loss S/N Ratios

Source	DF	Seq SS	Adj SS	Adj MS	Contribution
A	3	5.394	5.394	1.798	12.755
B	3	5.927	5.927	1.976	14.015
C	3	11.369	11.369	3.790	26.884
D	3	10.439	10.439	3.480	24.685
Residual error	3	9.160	9.160	3.053	21.660
Total	15	42.289			100

From the ANOVA table 4.5, it is observed that sliding distance influences 26.884% followed by Load 12.755%, track diameter 24.685%, sliding speed 14.015% respectively on %Wt loss.

4.4. S/N Ratio Analysis for Surface Roughness.

Higher values of the (S/N) signal-to-noise ratio identify control factor settings that minimize the effects of the noise factors.

The signal-to-noise ratio measures how the response varies relative to the nominal or target value under different noise conditions. For static designs, Minitab offers four signal-to-noise ratios. The goal of this experiment is to have low %Wt loss, so smaller the better S/N ratios are selected in this case.

$$S/N = -10 * \log (\Sigma (Y^2)/n))$$

The graph shown in Fig 4.2, gives the effect of each parameter on the response Surface roughness. First, the S/N ratio mean is calculated for each level of each parameter and then a plot is generated as show below to show at which level of each parameter the mean of S/N ration is higher. The level at which level of each parameter the mean of S/N ration is higher. The level at which the S/N ratio is higher will give the higher signal for the required response, Surface roughness in this case. That particular level of each parameter is taken as the optimal parameter for Surface roughness, as per Taguchi optimization.

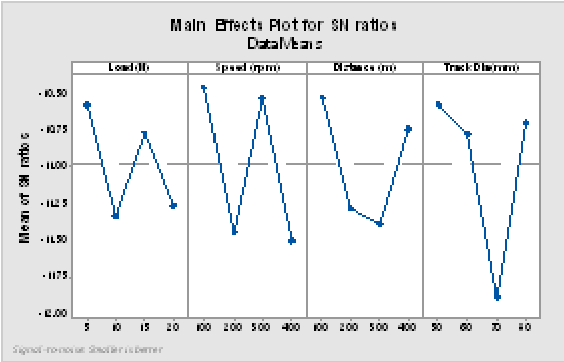

Fig 4.1: Effect of control factors on Surface roughness of Ti6Al4V.

Table 4.6 shows the Response Table for S/N Ratios of Surface roughness. Optimal parameters from the below table by Taguchi design for surface roughness are load=5N, sliding speed=400 rpm, sliding distance=400 m, track diameter=80 mm.

Table 4.6: Response Table for S/N Ratios (smaller is the better)

Level	Load(N)	Sliding Speed (rpm)	Sliding Distance (m)	Track Diameter (mm)
1	-10.57	-10.46	-10.52	-10.57
2	-11.34	-11.45	-11.28	-10.77
3	-10.76	-10.53	-11.39	-11.89
4	-11.26	-11.50	-10.74	-10.70
Delta	0.76	1.04	0.87	1.32
Rank	4	2	3	1

4.4.1 Predicted Surface Roughness:

Predicted S/N ratio = Y + (Load1-Y)
+ (Sliding Speed4 – Y)
+ (Sliding Distance4 –Y)
+ (Track Diameter4-Y)

Where Y= Average of S/N ratio Values for Surface Roughness i.e.

Y= (SN+SN2+SN3+SN4+SN5+SN6+...SN16)/16

Y= -10.9834.

Distance, Speed, Load, Track diameter values are taken from the response Table 4.6.

Predicted S/N ratio = -10.98348
+ (-10.57-(-10.98348))
+ (-10.46-(-10.98348))
+ (-10.52-(10.98348))
+ (-10.57-(-10.98348))

Predicted S/N ratio = -9.1695 (smaller the better)

For Smaller-the-Better

$S/N \text{ ratio} = -10 \log (MSD)^2$

$-9.1695 = -10 \log (\text{Surface Roughness})^2$

Surface Roughness = 10.629(Predicted value)

4.4.2 Analysis of Variance for *Surface Roughness*:

Analysis of variance (ANOVA) is used in order to find out the Percentage of contribution of each process parameter on Surface Roughness of Ti6Al4V.

Table 4.5: Analysis of Variance for Surface roughness S/N Ratios

Source	DF	Seq SS	Adj SS	Adj MS	Contribution
A	3	1.681	1.681	0.5604	10.475
B	3	3.869	3.869	1.2898	24.109
C	3	2.104	2.104	0.7014	13.111
D	3	4.444	4.444	1.4814	27.692
Residual error	3	3.949	3.949	1.3164	24.607
Total	15	16.048			100

From the ANOVA table 4.5 it is observed that track diameter influences 27.692% is followed by sliding speed 24.109%, sliding distance 13.111% and load 10.475% respectively on Surface Roughness.

V. CONCLUSION

In this present work, two performance parameters %Weight Loss and Surface Roughness are investigated by varying the four Process parameters on Ti6Al4V specimens which are incise by using wire electric discharge machine with Zinc coated Brass wire as electrode. The performance parameters included applied load, sliding speed, sliding distance and track diameter. Experiments were conducted according to Taguchi Design. The optimum parameters value combination was found which would yield minimum % Weight Loss and minimum Surface Roughness

Taguchi Design in Minitab software is used for optimization of the %Weight Loss and Surface Roughness.

%Weight loss 0.890 is observed to be minimum based on Taguchi Design of Experiments at the following parameters during the pin on disc wear test. Load=20N, speed=100 rpm, distance=400 m and track diameter=60 mm.

Surface roughness 2.905 is observed to be minimum based on Taguchi Design of Experiments at the following parameters. Load=5N, speed=100 rpm, distance=100m and track diameter=50mm.

Experimental values and Predicted values obtained by Taguchi Design are good in agreement with less than 10% error.

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