OPTIMIZATION OF PROCESS PARAMETERS OF WIRE ELECTRICAL DISCHARGE MACHINING OF Ti6Al4V ALLOY USING TEACHING-LEARNING-BASED OPTIMIZATION

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Abstract

Wire-cut electrical discharge machining (WEDM) process is non-traditional type machining process. The material is removed by thermo-electric spark erosion process. Wire EDM machines can cut conductive metals of any hardness that are difficult or impossible to cut with the conventional methods. Titanium grade5 (Ti6Al4V) material is selected as a workpiece material. Ti6Al4V material is used in many applications such as, aerospace, medical, military and other commercial application because of its high strength to weight ratio and its exceptional resistance to corrosion at elevated temperature. Brass wire and diffusion zinc coated wire is used as wire electrode material. The objective of this study is to find relation between process parameters such as pulse on time, pulse off time, peak current, wire tension and servo voltage for the cutting rate & surface roughness. Regression analysis is use to generate the equations for responses. Teaching-Learning-Based optimization (TLBO) algorithm is used to find the optimum values of process parameters. Optimum values of the parameters are obtained by the TLBO method.

Keywords: *WEDM, Optimization, Ti6Al4V, Cutting rate, Surface roughness, TLBO*

1. INTRODUCTION

Wire-electrical discharge machining (WEDM) is a non-traditional machining process in which the material is removed by the thermo-electric spark erosion process. WEDM process can be used to cut any electrical conductive metal and alloys regardless of their hardness. In WEDM process, thin wire electrode is used, which transforms electrical energy into thermal energy to cut the material. The wire electrode does not touch the workpiece, but there is a small gap between the workpiece and the wire electrode. Therefore there is no mechanical stress produces during the process. The wire is kept in tension with the help of mechanical tensioning device, to decrease the tendency of producing incorrect parts.

The WEDM machine tool mainly contains four major components which are computer numerical control (CNC), power supply, mechanical section and dielectric system. The mechanical section mainly consists of main work table (X-Y), auxiliary table (U-V) and wire drive mechanism. The electrical spark is generated by the pulse generator unit. The spark is generated in the small gap between the workpiece and the wire. The machining zone is constantly flushed by the dielectric fluid by the upper and lower nozzle on the both sides of workpiece. The deionized water is use as dielectric medium due to its low viscosity and fast cooling rate. The schematic diagram of basic principle of WEDM process is shown in fig. 1.

The electrical discharge spark is continuous generated between workpiece and wire electrode. The material is removed because of melting and vaporization caused by sparks. The temperature generated is around 8000° C to 12000° C, therefore material is vaporize and melt.

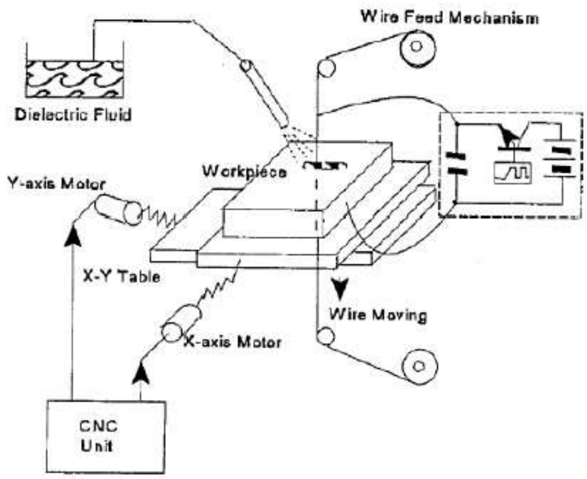

Fig. 1 Schematic diagram of basic principle of WEDM process

1.1 Literature Review

In this part, the literature review regarding the optimization of the process parameters of WEDM process is carried out. Optimum utilization of the capabilities of WEDM process requires the selection of an appropriate set of machining parameter.

Sonu Dhiman et al. The effect of different process parameters like, pulse on time, pulse of time, servo voltage, peak current, wire feed, wire tension on cutting rate of S7 steel is studied. One factor at a time (OFAT) method is used to find the effects on responses [1]. R. Venkata Rao et al. This paper gives brief idea about TLBO algorithm. In this paper comparison between other optimization techniques and TLBO algorithm is given. TLBO algorithm is better than the other optimization algorithm in terms of results [2]. Kuriachen Basil et al. In this study the effect of voltage, dielectric process, pulse on time and pulse off time on spark gap of Ti6Al4V alloy is studied. Full factorial method is used [3]. Aniza Alias et al. The objective of this paper is to find effect of different machine feed rates with constant current (6A) on Ti6Al4V. If machine feed rate is increase, the MRR and Kerf width increases. Smoother surface roughness is obtain with low machine feed rate [4]. M. T. Antar et al. This study investigates the effect on productivity and surface integrity with the use of coated wires and uncoated wires. Comparison between Cu core coated wires and uncoated brass wire for two workpiece materials Udimet 720 nickel based super alloy and Ti-6Al-2Sn-4Zr-6Mo titanium alloy is given. The productivity of both workpiece material increase significantly with the use of coated wires [5]. C V S Parmeswara Rao et al. In this paper, the effect of discharge current, voltage at rated wire speed and tension on MRR, surface roughness, cutting speed and spark gap is studied. Mathematical relations are developed for cutting speed & workpiece thickness and for spark gap & workpiece thickness which are useful to estimate cutting time [6]. Nihat Tosun et al. effect of machining parameters on the kerf width and MRR by Taguchi experimental design method. ANOVA method is used to find significant parameters and optimum machining parameter combination was obtained by S/N ratio. The objective is to find minimum kerf with maximum MRR [7]. Nihat Tosun and Can Cogun, This paper investigate the effect of cutting parameter on wire electrode wear. The process parameters selected are pulse duration, open circuit voltage, wire speed and dielectric fluid pressure. ANOVA is also used in this study. It is found that by increasing open circuit voltage and pulse duration, wire wear rate increases. WWR can be decrease by increasing the dielectric fluid pressure & wire speed [8].

The purpose of this study is to carry out the experiments on Ti6Al4V by changing the wire material. Mathematical relationship between input parameters and response is generated with the help of regression analysis. Find the optimum values of the process parameters by TLBO technique.

2. EXPERIMENTAL WORK AND RESULTS

A wire-cut EDM machine (ELEKTRA SPRINTCUT 734) of Electronica Machine Tools Ltd. installed at Surelia wire-cut Pvt Ltd, Rajkot is use for the experimental work. Titanium grade 5 (Ti6Al4V) is taken as workpiece material. It has high strength to low weight ratio and outstanding corrosion resistance. Therefore it can be used in many applications. Also Ti6Al4V is most utilized titanium alloy. Ti6Al4V is used in many applications such as aerospace industry, biomedical applications, marine components, chemical industry etc. Table 1 shows the workpiece specification.

Table 1 Workpiece specification

No.	Workpiece Specification	
1	Material	Ti6Al4V Titanium grade 5
2	Grade	5
4	Thickness	4 mm
5	Width and Length	300 mm * 20 mm
6	Chemical composition	Al – 5.5 to 6.75 % V – 3.5 to 4.5 % Fe – 0.1 to 0.3 % Mo – 0.1 to 0.2 % Mn – 0.002 to 0.003 % Ti – Balance

In this work two types of wire materials are used as wire electrode for the WEDM process of Ti6Al4V material. Experiments are carried out by brass wire and diffusion zinc coated brass wire.

2.1 Selection of process parameters

Selection of the process parameters is based on the literature survey. For the selection of the levels of parameter different range of the parameter should be known. In this work, five process parameters are selected to study its effects on cutting rate and surface roughness. Selected process parameters and their three levels are shown in table 2.

Following parameters were kept constant during the experimental procedure.

1. Work material: Titanium grade 5, Ti6Al4V
2. Wire feed: 4 m/min
3. Servo feed: 2050 unit
4. Flushing pressure: 5 Kg/cm^2
5. Workpiece thickness: 4 mm
6. Peak voltage: 2 unit (110 Volt DC)

Table 2 Process parameters with their levels

Parameter	Level 1	Level 2	Level 3
Pulse-on time (T_{on})	105	116	128
Pulse-off time (T_{off})	14	36	52
Peak current (IP)	70	150	230
Wire tension (W_t)	5	10	15
Servo voltage (SV)	20	50	80

Minitab 16.0 software is used for design of experiments. In the Minitab 16.0 software there are several methods available to perform design of experiments like Taguchi design, Factorial design, Response surface method and

Mixture design. Taguchi method is simple and the strength of the Taguchi method is that one can change many variables at a time and still have control over the experiments. The Design of experiments are conducted using Taguchi's method. it will give Taguchi's L27 orthogonal array (OA) for five process parameters and three levels.

2.2 Results obtained after experiments

Table 3 Results obtained after experiments by brass and diffusion zinc coated wire

No.	T_{on}	T_{off}	IP	W_t	SV	For BRASS wire		For DIFFUSION ZINC COATED WIRE	
						Cutting rate (mm/min)	Surface roughness Ra (µm)	Cutting rate (mm/min)	Surface roughness Ra (µm)
1	105	14	70	5	20	0.9312	1.94	1.8807	1.45
2	105	14	70	5	50	0.9064	1.93	1.7836	1.38
3	105	14	70	5	80	0.9021	2.05	1.8167	1.33
4	105	36	150	10	20	1.1799	1.95	2.3174	1.77
5	105	36	150	10	50	1.1757	1.97	2.5478	1.66
6	105	36	150	10	80	1.3204	2.03	2.5873	1.55
7	105	52	230	15	20	1.5936	2.02	3.2103	2.04
8	105	52	230	15	50	1.4054	2.21	2.7548	1.85
9	105	52	230	15	80	1.2964	2.01	2.8222	1.64
10	116	14	150	15	20	1.9912	2.45	4.2956	2.15
11	116	14	150	15	50	2.0598	2.42	4.186	2.09
12	116	14	150	15	80	1.6835	2.44	4.1478	2.03
13	116	36	230	5	20	2.6041	2.53	4.0404	2.49
14	116	36	230	5	50	2.6397	2.55	3.4305	2.35
15	116	36	230	5	80	2.6143	2.49	3.8444	2.34
16	116	52	70	10	20	2.3972	2.29	3.9216	2.13
17	116	52	70	10	50	2.2041	2.32	4.0553	2.08
18	116	52	70	10	80	1.88702	2.1	3.8095	1.88
19	128	14	230	10	20	2.5494	2.62	4.6729	2.5
20	128	14	230	10	50	2.5873	2.72	4.8426	2.43
21	128	14	230	10	80	3.003	2.82	4.8780	2.61
22	128	36	70	15	20	2.2701	2.5	4.7506	2.21
23	128	36	70	15	50	2.2727	2.55	4.7619	2.12
24	128	36	70	15	80	2.3228	2.5	4.6948	2.22
25	128	52	150	5	20	3.0395	2.55	4.7619	2.45
26	128	52	150	5	50	3.0487	2.58	4.8077	2.65
27	128	52	150	5	80	3.0864	2.51	4.3860	2.53

2.3 Main effect plots for data means

The main effect plots are generated with the help of MINITAB 16 software. The main effect plot shows the relation of the parameters with responses.

Fig. 2 shows the main effect plots for data means values for cutting rate and surface roughness for the brass wire material. From fig. 3, it can be seen that by increasing the value of pulse on time and peak current, cutting rate increases. The surface finish decreases with increasing the value of peak current and pulse on time.

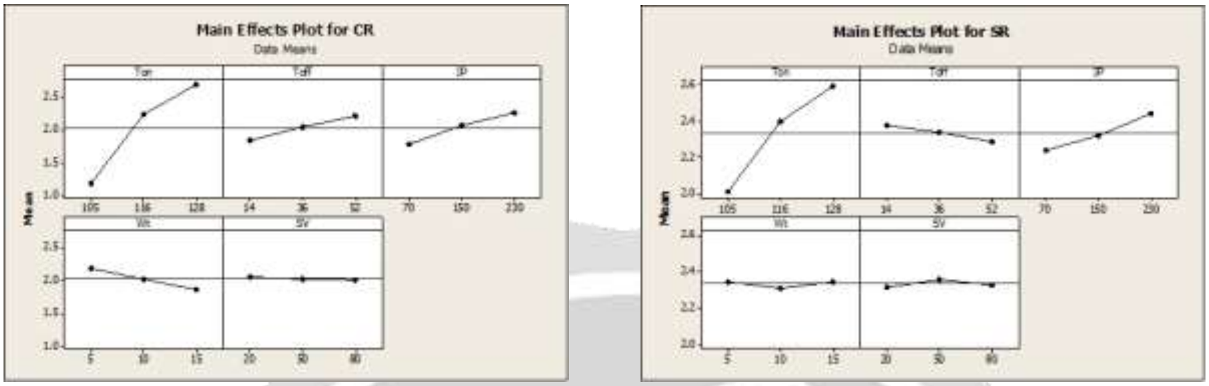

Fig. 2 Main effect plots for Cutting rate and surface roughness (Brass wire)

Fig. 3 shows the main effect plots for data means values for cutting rate and surface roughness respectively for the diffusion zinc coated wire material. Surface finish decreases with increase in pulse on time and peak current. Cutting rate is highly affected by pulse on time and peak current.

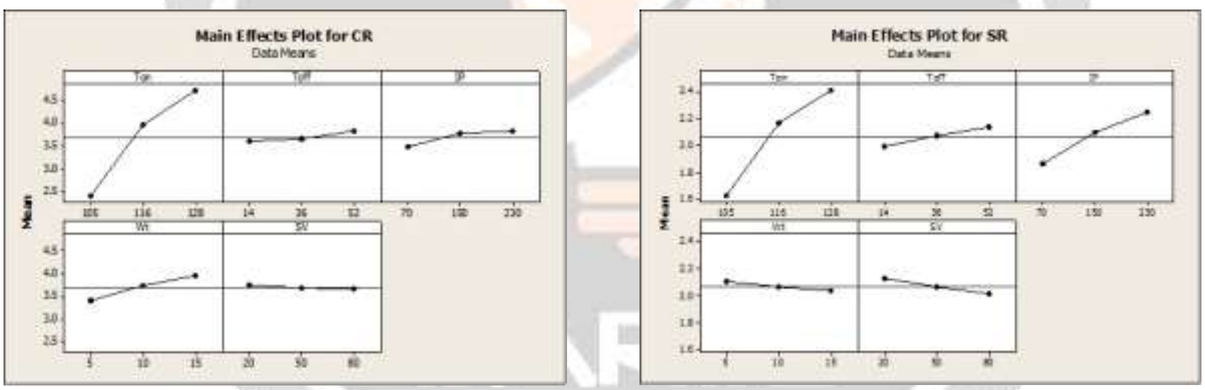

Fig. 3 Main effect plots for Cutting rate and surface roughness (Diffusion zinc coated wire)

2.4 Analysis of results

Table 4 Result table

Response	Unit	Brass wire		Diffusion zinc coated wire	
		Min	Max	Min	Max
Cutting rate	mm/min	0.9021	3.0864	1.7836	4.8780
Surface Roughness	µm	1.93	2.82	1.33	2.65

From above table we can conclude the following things.

Cutting rate: The value of the cutting rate is very important for any material to be cut rapidly. Brass wire gives highest cutting rate value of 3.0864 mm/min from the combination of input parameters. Diffusion zinc coated wire gives highest cutting rate value of 4.8780 mm/min from the combination of input parameters. Thus diffusion zinc coated wire material is the most desirable wire material for maximum cutting rate.

Surface roughness: the surface roughness should minimum for any material to get better surface finish. Maximum surface roughness value for brass wire and diffusion zinc coated wire material is 2.82 µm and 2.65 µm respectively. Minimum surface roughness value for brass wire and diffusion zinc coated wire material is 1.93 µm and 1.33 µm. Thus diffusion zinc coated wire is desirable to use.

3. REGRESSION ANALYSIS

Regression analysis is statistical process which gives selection between the input parameters and output. Regression analysis gives output in such a way to fit the linear, quadratic, cubic, polynomial and non-linear curves. Regression analysis gives the correlation among the dependent variable and independent variable. The regression analysis can be done using Microsoft office Excel and also by the Minitab software. In this work, Minitab 16.0 software is used for linear regression. I have used linear regression analysis equation. On giving data table achieved from the experiments to the Minitab software it gives the following results.

For Brass wire material,
Cutting Rate = - 5.89 + 0.0647 Ton + 0.00973 Toff + 0.00292 IP - 0.0320 Wt - 0.00082 SV
R-Sq = 92.0%
Surface Roughness = - 0.708 + 0.0252 Ton - 0.00230 Toff + 0.00124 IP - 0.00033 Wt + 0.000185 SV
R-Sq = 90.9%

For Diffusion zinc coated wire material,
Cutting Rate = - 8.91 + 0.100 Ton + 0.00571 Toff + 0.00210 IP + 0.0541 Wt - 0.00160 SV
R-Sq = 93.4%
Surface Roughness = - 2.19 + 0.0338 Ton + 0.00374 Toff + 0.00240 IP - 0.00689 Wt - 0.00196 SV
R-Sq = 91.7%

4. OPTIMIZATION USING TLBO

TLBO is a teaching-learning motivated algorithm based on effect of influence of a teacher on the output of learners in a class. Teaching-learning Based optimization (TLBO) is nature based optimization algorithm and solve various optimization problems efficiently. In TLBO, there are mainly two phases, one is teacher phase and another is learner phase. Output is taken in terms of results or grades. The teacher is taken as highly learned person. Teacher gives his or her knowledge to learners. The learner's outcome is depending on the quality of the teacher. Therefore good teacher trains learners for the good results in form of marks or grades. [2]

4.1 Teacher phase

A good teacher increases the level of learners' up to his or her level in terms of knowledge. But it is depending on the level of learners. This follows a random process depending on many factors. Now, M_i is the mean and T_i is the teacher at any iteration i. T_i will try to move M_i near its own level. Therefore new mean will be T_i labeled as M_{new}. The solution is updated according to the difference among the existing and the new mean is [9]

$$\text{Difference\_Mean}_i = r_i\ (M_{new} - T_F M_i)$$

Here, T_F = teaching factor that decides the value of mean to be changed

r_i = random number in the range [0,1]

The value of T_F can be either 1 or 2, which is again a heuristic step and decided randomly with same probability as, T_F = round [1+ rand (0, 1) {2-1}]

Now, this difference modifies the existing result according to the below expression.

$$X_{new,i} = X_{old,i} + \text{Difference\_Mean}_i$$

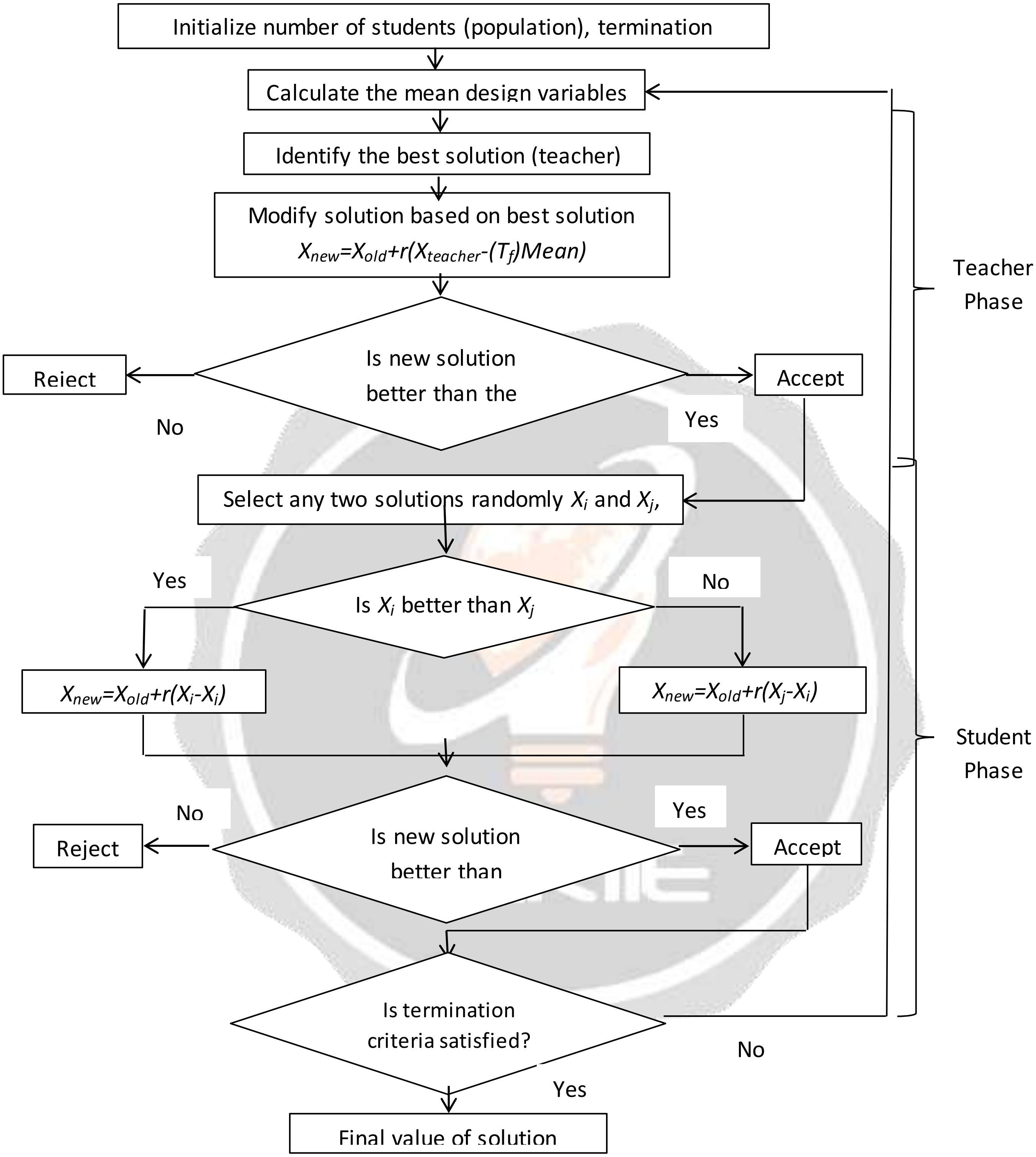

Fig. 4 Flow chart of the working of TLBO algorithm [9]

4.2 Learner phase

In this phase, the knowledge of learners is increases by teacher and also by the interaction among themselves. A learner will gain knowledge if the other learner has more knowledge than him or her. The learners phase is expressed as below.

For i = 1:Pn
Randomly select two learners X_i and X_j, where, $i \neq j$
If $f(X_i) < f(X_j)$
$X_{new,i} = X_{old,i} + r_i(X_i - X_j)$
Else
$X_{new,i} = X_{old,i} + r_i(X_j - X_i)$
End If
End For
Accept X_{new} if it gives a better function value.

2.3 Multi-objective optimization

Optimization can be defined as process of selecting optimum values of variables which gives the best suitable values of objective function. Optimization can be of single objective or multi-objective type. The optimization process is can be of minimization type or maximization type.

In this research work there are five variables namely pulse on time, pulse off time, peak current, wire tension and servo voltage. The outputs are cutting rate and surface roughness. Weight method is used for the multi-objective optimization. Cutting rate and surface roughness are the two different sub-objectives. The function is normalized to solve multi-objective problem.

2.4 Multi-objective function and limit of variables

I. For brass wire material,
The first objective is to maximize the cutting rate. The equation for the cutting rate is
$CR_1 = -5.89 + 0.0647\ Ton + 0.00973\ Toff + 0.00292\ IP - 0.0320\ Wt - 0.00082\ SV$
The second objective is to minimize the surface roughness. The equation for the surface roughness is
$SR_1 = -0.708 + 0.0252\ Ton - 0.00230\ Toff + 0.00124\ IP - 0.00033\ Wt + 0.000185\ SV$

The above given single objective functions are mentioned together for multi-objective optimization. The normalized multi-objective function (Z) is formulated by giving weight factors in equation.

Maximize $Z_1 = w\,(CR_1 / CR_{1,max}) - (1-w)\,(SR_1 / SR_{1,max})$
Here w = weight factor for the equation. $CR_{1,max}$ and $SR_{1,max}$ are the maximum and minimum values of the objective functions CR_1 and SR_1 respectively.

II. For diffusion zinc coated wire material,
The first objective is to maximize the cutting rate. The equation for the cutting rate is
$CR_2 = -8.91 + 0.100\ Ton + 0.00571\ Toff + 0.00210\ IP + 0.0541\ Wt - 0.00160\ SV$

The second objective is to minimize the surface roughness. The equation for the surface roughness is
$SR_2 = -2.19 + 0.0338\ Ton + 0.00374\ Toff + 0.00240\ IP - 0.00689\ Wt - 0.00196\ SV$

The normalized multi-objective function (Z) is,
Maximize $Z_2 = w\,(CR_2 / CR_{2,max}) - (1-w)\,(SR_2 / SR_{2,max})$
Here w = weight factor for the equation. $CR_{2,max}$ and $SR_{2,max}$ are the maximum and minimum values of the objective functions CR_2 and SR_2 respectively.

The limits of the variable parameters are given as below,

$$105 \le T_{on} \le 128$$
$$14 \le T_{off} \le 52$$
$$70 \le IP \le 230$$
$$5 \le W_t \le 15$$
$$20 \le SV \le 80$$

The multi-objective function is not depending on any constraints. Therefore it is of unconstrained type problem and for that the codes are given to the MATLAB for the optimization using TLBO algorithm.

The code is applied in MATLAB and modifications and some changes are done as per the problem and objective function.

3.Results after optimization using TLBO algorithm in MATLAB

After completing 500 iterations the optimum values of the multi-objective for the variables are given below. The population is taken as 35 in the program. The weight factor is considered as per the requirement. Here the value of w is considered as 0.6. Figure 5 and 6 shows the values for the responses at 500 runs for brass wire and diffusion zinc coated wire respectively.

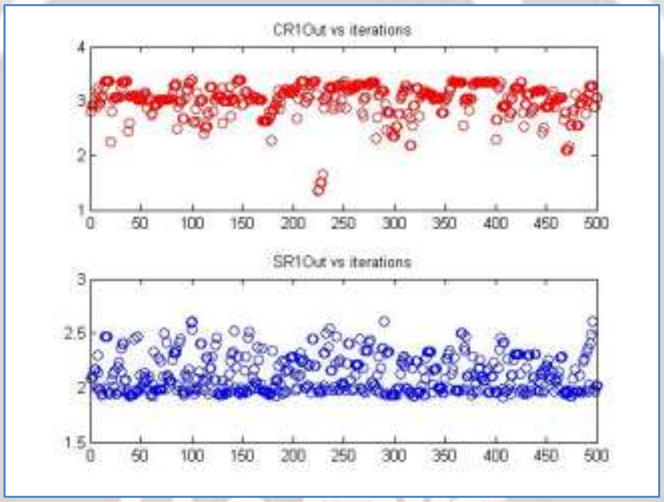

Fig. 5 Result values of the responses v/s iterations for brass wire

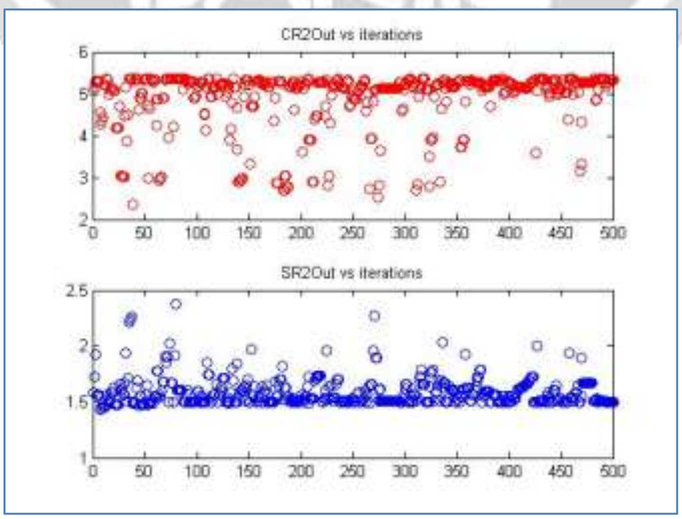

Fig. 6 Result values of the responses v/s iterations for diffusion zinc coated wire

Optimum values after computation using program are as below.
For brass wire
T_{on} = 128.00 T_{off} = 52.00 IP = 230.00 W_t = 5 SV = 49.70 = 50
Cutting rate, CR_1= 3.37 mm/min
Surface roughness, SR_1= 2.69 µm

For diffusion zinc coated wire material,
T_{on} = 128.00 T_{off} = 52.00 IP = 230.00 W_t = 15 SV = 80
Cutting rate, CR_2= 5.35 mm/min
Surface roughness, SR_2= 2.62 µm

The above given values are the final values for the multi-objective optimization of cutting rate and surface roughness for the given set of the input variables.

5. CONCLUSION

The optimum value for the process parameters is obtained from the TLBO algorithm in MATLAB for the both wire material. The values are confirmed by experiments carried out at industry. The experimental values and theoretical values vary slightly for the objective function.

From the experimental and research work, the best suited values of process parameters are T_{on} = 128.00 machine unit, T_{off} = 52.00 machine unit, IP = 230.00 A, W_t = 5 machine unit, SV = 50 V for brass wire material. For diffusion zinc coated wire material the values of process parameters are T_{on} = 128.00 machine unit, T_{off} = 52.00 machine unit, IP = 230.00 A, W_t = 15 machine unit, SV = 80 V. The diffusion zinc coated wire material gives the best result for the cutting rate and surface roughness. Thus it should use for the WEDM process of the Ti6Al4V material.

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