Journal of Material Science and Mechanical Engineering (JMSME)
p-ISSN: 2393-9095; e-ISSN: 2393-9109; Volume 2, Issue 13; October-December, 2015 pp. 50-54

http://www.krishisanskriti.org/Publication.html

Effect of Machining Parameters on Wire Electro Discharge Machining of Shape Memory Alloys Analyzed using Grey Entropy Method

Hargovind Soni[1], Narendranath S.[2] and Ramesh M.R.[3]

[1,2,3]National Institute of Technology, Karnataka
E-mail: [1]hargovindsoni2002@gmail.com, [2]narenbayalu@gmail.com, [2]ramesdmt@gmail.com

Abstract—*Last few decades have a rapid growth in the development of harder and difficult to machine materials such as shape memory alloys, heat treated tool steels, composites, wasplloy, nimonics, carbides, stainless steel, heat resisting steels & many other high strength- temperature resistant (HSTR) alloys, which are widely used in aerospace, nuclear engineering, aeronautics, biomedical industries. It has been realized that such material are difficult to machine by conventional methods and to achieve required surface finish and material removal rate. Wire Electro discharge machining (WEDM) is a thermal erosion process where material is removed from the work piece by series of sparks between tool and workpiece immersed in a dielectric fluid. The present work aimed at determining the optimal process parameters for machining of* $Ti_{50}Ni_{39}Cu_{11}$ *(wt %) shape memory alloys on WEDM machine, where material removal rate (MRR) was maximized without compromising surface roughness (SR). The designed experimental results are used in the gray relational analysis & the weight of the quality characteristics are determined by the entropy measurement method. The effects of the parameters on the responses were evaluated by response surface methodology, which is based on optimization results. The best results for MRR and SR are achieved for the machining parameters of Pulse on Time (Ton) = 120µs, Pulse of time (Toff) =48µs, Spark Gap voltage (SV) =60v, Servo Feed (SF) =2180mu and Wire speed (WS) = 5mm/m.*

Keywords*: Wire Electro discharge machining; Grey entropy method, Surface roughness; Material removal rate; HSTR alloys*

1. INTRODUCTION

In current years, the advanced engineering materials such as TiNi based shape memory alloys (SMAs) are normally used in medical devices, surgical instruments, and industrial engineering applications. In the medical applications include surgical stents, orthodontic arch wires etc. The various industrial engineering applications are the functional devices such as sealing and coupling, fasteners, sensors and micro electromechanical devices (MEMS), aerospace actuators, and fuel injector [2]. SMAs exhibit excellent properties such as fast actuation response, unique properties like shape memory effect (SME), and super plasticity, corrosion resistant, high wear resistance, greater ductility and high specific strength, good fatigue property and high bio-compatibility [3,4]. SMAs are typically known for SME and pseudoelasticity (PE) properties [2, 5].

With the growth of technology and industries , harder and difficulties to machine material are developed, which are largely used in aeronautics , nuclear energy , aerospace, die and mould making industries. The machining of these materials is very difficult by traditional machining process. In recent years non-traditional machining process play an important role in manufacturing of these material in industries. EDM is that the mainstay of non-traditional manufacturing process, it plays a vital role in matching those difficult to machine materials, which user other sources of energy instead of direct tool workpiece contact. The metal is removed in EDM owing to erosion caused by rapidly occurring discharge between tool and workpiece. The limitation being the work material should be conductive [1].

There are several parameters, which influence this process; however, some parameters are most influential. In this research and attempts have been made to see the effect of these parameters on the responses. Using this parameter (Ton, Toff, SV, SF, WS) in this study was optimized for MRR, and Surface Roughness, is very good.

2. EXPERIMENTAL

Ti50Ni49Cu11 SMA prepared by using vacuum arc melting (VAM) technique. Titanium, nickel and copper with a purity of 99.2, 99.89 and 99.89 respectively of 8 g in total weight were filled into the copper mold and then processed by inert argon atmosphere using a tungsten electrode. The pure metal rods (Ti, Ni and Cu) were cut into very small pieces, weighed using an electronic balance (0.0001 g accuracy) and then charged into the furnace for button melting operation. A vacuum was created using the standard procedure up to 10−5 mbar and then argon gas was purged into the chamber. Pumping the system flushed out the gas and the procedure for vacuum creation was carried out to achieve a very good vacuum of 10−5 mbar and then followed by backfilling of argon gas. This is done in order to remove any impurities present in the chamber.

For conducting the experiments a Wire EDM (model Electronica ELPULS15 CNC) was used, the response used for this study was MRR and SR are correlated with machining parameter such as Pulse on Time (Ton), Pulse of time (Toff), Spark Gap voltage (SV), Servo Feed (SF) and Wire speed (WS) were identified and the ranges for each of process parameters were determined through preliminary experiments. Each process (input) parameter was investigated at five levels to study the non-linear effect of the process parameters and the selected parameters as well as their identified levels for single pass cutting operation during WEDM of TiNi based SMA and the proposed experimental design matrix planned as per L25 orthogonal array (OA) for the current investigation is presented in Tables 1 and 2 respectively. In this machining deionized water as dielectric fluid with pressure 12 kg/cm2, Brass wire (diameter of 0.25) mm and 900 g-wire tension were kept constant throughout the experimentation.

Table 1: Input parameters and their levels

Level	T_{on} (µs)	T_{off} (µs)	SV (V)	SF (mu)	WS (m/min)
1	100	48	20	2160	2
2	105	52	30	2170	3
3	110	56	40	2180	4
4	115	60	50	2190	5
5	120	64	60	2200	6

Table 2: Experimental results for five variables in coded units

S. no.	Ton	Toff	SV	SF	WS	MRR	SR
1	100	48	20	2160	2	9.98	2.61
2	100	52	30	2170	3	10.21	3.01
3	100	56	40	2180	4	11.09	2.99
4	100	60	50	2190	5	5.296	1.98
5	100	64	60	2200	6	4.83	1.66
6	105	48	30	2180	5	5.01	1.79
7	105	52	40	2190	6	2.13	2.23
8	105	56	50	2200	2	2.47	2.51
9	105	60	60	2160	3	2.236	1.89
10	105	64	20	2170	4	4.053	1.84
11	110	48	40	2200	3	4.2	1.94
12	110	52	50	2160	4	4.006	1.89
13	110	56	60	2170	5	10.01	2.03
14	110	60	20	2180	6	9.69	3.34
15	110	64	30	2190	2	9.94	2.99
16	115	48	50	2170	6	6.064	2.11
17	115	52	60	2180	2	7.01	2.15
18	115	56	20	2190	3	7.304	2.16
19	115	60	30	2200	4	11.121	2.32
20	115	64	40	2160	5	11.99	2.05
21	120	48	60	2180	4	12.64	2.71
22	120	52	20	2200	5	3.105	1.61
23	120	56	30	2160	6	3.18	2.12
24	120	60	40	2170	2	3.22	1.81
25	120	64	50	2170	3	11.43	3.41

3. METHODOLOGY

3.1 Response Surface Method

In statistics, Response surface methodology (RSM) investigates the interaction between several illustrative variables and one or more response variables. Box and Draper were introducing RSM in 1951[22].The most important proposal of RSM is to use a series of designed experiments to attain an optimal response. A second-degree polynomial model is use in RSM. These models are only an approximation, but use it because such a model is easy to estimate and apply, even when little is known about the process. This model is known as quadratic model, which is as follows:-

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i,j=1,\ i\neq j}^{k} \beta_{ij} X_i X_j + \varepsilon..I$$

Where ε is the noise or error observed in the response Y. Xi is the linear input variables, X2ii and XiXj are the squares and interaction terms, respectively, of these input variables. The unknown second order regression coefficients are βo, βi, βij and βii, which should be determined in the second-order model, are obtained by the least square method.

The process of RSM includes designing of a series of experiments for sufficient and reliable measurement of the response and developing a mathematical model of the second order response surface with the best fittings. Obtaining the optimal set of experimental parameters, thus produce a maximum or minimum value of the response. The Minitab Software was used to analyze the data [7].

3.2 Grey Relational Analysis

Initiator of the Grey system theory (1982) was Deng [8]. In grey system theory includes three types of systems first black which shows no information in this system, second white which shows all information in this system & third grey system which shows imperfect information. The grey system theory is an efficient technique, which requires limited information to estimate the behavior of an uncertainty system & discrete data problem [6].

If the sequences range is large, in GRA, the factors are effaceable. Although, if the measured factors are discrete, then wrong results may be produce by GRA. So, for evade this influence, must perform data per- processing of original experimental data. The range of data processing is zero to one (0-1). Normalizing involves transforming the original sequence to comparable sequence. This is known as grey relational generating. In this study, normalization of the experimental results attained for MRR and SR.

There are three conditions of normalization-

1) lower is better
2) higher is better
3) nominal the best

But in this study only two conditions are required, lower is better & higher is better.

The normalization is taken by the following equations

Higher is better

$$X_i^*(k) = \frac{X_i(k) - \min X_i(k)}{\max X_i(k) - \min X_i(k)} ..II$$

Lower is better

$$X_i^*(k) = \frac{\max X_i(k) - X_i(k)}{\max X_i(k) - \min X_i(k)} ..III$$

Nominal the best

$$X_i^*(k) = \frac{1 - |X_i(k) - X_0 b(k)|}{\max X_i(k) - X_0 b(k)} ..IV$$

where I = 1, 2n, k = 1, 2, y, p; X*i (k) is the normalized value of the kth element in the ith sequence, X0b (k) is desired value of the kth quality characteristic, max X*i (k) is the largest value of Xi(k), and min X*i (k) is the smallest value of Xi(k), n is the number of experiments and p is the number of quality characteristics.

After the normalization, calculated grey relational co-efficient, which shows the interaction between optimal & actual normalized experimental results. GRC can be presented-

$$\gamma_i(k) = \gamma(x_0(k)) = \frac{\Delta \min + \zeta \Delta \max}{\Delta_{0,i}(k) + \zeta \Delta \max} ..V$$ I=1; . . . ; n; k= 1; . . . ; p

Where Δ0,i(k) = |x0(k)−xi(k)| is the difference of the absolute value called deviation sequence of the reference sequence x0(k) and comparability xi(k). The ξ is the distinguishing coefficient or identification coefficient. In general, it is set to 0.5. The GRG is a weighting-sum of the grey relational coefficients and it is defined as-

$$\gamma(x_{0,} x_i) = \sum_{n}^{k=1} \beta_k (x_{0,} x_i) ..VI$$

Where βk represents the weighting value of the k^{th} performance characteristic, and $\sum_n^{k=1} \beta_k = 1$.

3.3 Entropy Measurement Method

This is an objective weighting method. In GRA, determine the weights of each quality characteristics. Suggested by wen et al. [9] discrete type of entropy is used in grey entropy measurement for properly conduct weighting analysis. Entropy method is used for calculating gray relational grade. There are seven steps for calculations of weights of each characteristic [10]-

1. Compute the summation of each attribute's value for all sequences, D_k-

$$D_k = \sum_{i=1}^{m} x_i(k) ..VII$$

2. Compute the normalization coefficient K-

$$K = \frac{1}{(e^{0.5} - 1)n} ..VIII$$

Where n represents the number of attributes.

3. Find the entropy for the specific attribute, ek-

$$e_k = \frac{1}{K} \sum_{i=1}^{n} f(\frac{x_i(k)}{D_k} ..IX$$

4. Compute the total entropy value E-

$$E = \sum_{k=1}^{n} e_k ..X$$

5. Determine the relative weighting factor λ_k -

$$\lambda_k = \frac{(1 - e_k)}{n - E} XI$$

6. The normalized weight of each attribute can be calculated as-

$$\beta_k = \frac{\lambda_k}{\sum_{k=1}^{n} \lambda_i} XII$$

For calculation of GRG, grey relational co-efficient multiplying with corresponding weight of quality characteristics.

4. RESULT AND DISCUSSION

The experimental values are obtained from experiments conducted as per plan presented in Table no. 2. Normally, higher value of MRR and lower value and surface roughness are desired. Thus, the normalized equation no II is used for higher the better (MRR) and equation no III is used for lower the better for SR. In normalization, the original sequence must be normalized in the range of zero to one. The normalized value & deviation sequence are presented in table no. 3; calculation of grey relational co- efficient, grey relational grade & rank are given in table no. 4. The grey relational co-efficient was calculated from equation no. (V). Before calculating GRG, must be find wattage of each characteristic used by entropy measurement method. GRG calculated by equation no. (VI). Statistical analysis of GRG was performed by using Minitab software, and the main effect of process parameters on GRG are shown in Fig. no. 1.

Table 3: Normalization & Deviation sequence

Normalized value		Deviation sequence	
MRR	**SR**	**MRR**	**SR**
0.747	0.556	0.253	0.444
0.769	0.778	0.231	0.222
0.853	0.767	0.147	0.233
0.301	0.206	0.699	0.794
0.257	0.028	0.743	0.972
0.274	0.100	0.726	0.900
0.000	0.344	1.000	0.656
0.032	0.500	0.968	0.500
0.010	0.156	0.990	0.844
0.183	0.128	0.817	0.872
0.197	0.183	0.803	0.817
0.178	0.156	0.822	0.844
0.750	0.233	0.250	0.767
0.719	0.961	0.281	0.039
0.743	0.767	0.257	0.233
0.374	0.278	0.626	0.722
0.464	0.300	0.536	0.700
0.492	0.306	0.508	0.694
0.855	0.394	0.145	0.606
0.938	0.244	0.062	0.756
1.000	0.611	0.000	0.389
0.093	0.000	0.907	1.000
0.100	0.283	0.900	0.717
0.104	0.111	0.896	0.889
0.885	1.000	0.115	0.000

Table 4: Grey relational co-efficient, Grey relational grade and rank

GRC MRR	GRC SR	GRG	RANK
0.664	0.529	0.441	8
0.684	0.692	0.454	6
0.772	0.682	0.513	5
0.417	0.386	0.277	14
0.402	0.340	0.267	16
0.408	0.357	0.271	15
0.333	0.433	0.221	25
0.341	0.500	0.226	23
0.336	0.372	0.223	24
0.380	0.364	0.252	18
0.384	0.380	0.255	17
0.378	0.372	0.251	19
0.666	0.395	0.442	7
0.640	0.928	0.425	10
0.661	0.682	0.439	9
0.444	0.409	0.295	13
0.483	0.417	0.320	12
0.496	0.419	0.329	11
0.776	0.452	0.515	4
0.890	0.398	0.591	2
1.000	0.563	0.664	1
0.355	0.333	0.236	22
0.357	0.411	0.237	21
0.358	0.360	0.238	20
0.813	1.000	0.540	3

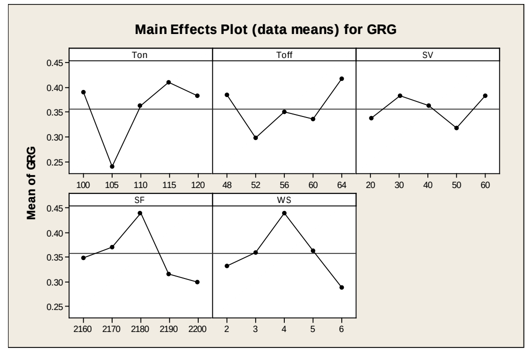

Fig. 1: Main effect of process parameters on GRG

5. CONCLUSION

In this study, the machining parameters of WEDM process have optimized by gray relational analysis combine with entropy measurement method. The influence of various process parameters is calculated and found that a Pulse on Time (T_{on}) = 120μs, Pulse of time (T_{off}) =48μs, Spark Gap voltage (SV) =60v, Servo Feed (SF) =2180mu and Wire speed (WS) = 5mm/m are the best parametric combination for the machining of $Ti_{50}Ni_{39}Cu_{11}$ (wt %) shape memory alloy. This analysis shows that the RSM, GRA and entropy analysis can be successfully implemented to find the best parametric combination. Further it can be used to other manufacturing process.

6. ACKNOWLEDGMENT

This work was supported by the Department of Science and Technology (DST) Government of India project reference SB/S3/MMER/0067/2013. Authors would like to thanks the DST for its funding support.

REFERENCES

[1] Prasad DVSSS V., Gopala Krishna a. (2009) Empirical modeling and optimization of wire electrical discharge machining. Int J Adv Manuf Technol 43:914–925. doi: 10.1007/s00170-008-1769-x.

[2] Wu MH, Schetky LM. Industrial applications for shape memory alloys. In: Proc Int Conf Shape Mem Superelastic Technologies. 2000. p. 171–82.

[3] Lin HC, Lin KM. A study of Fe–30Mn–6Si shape memory alloys prepared from Different melting techniques. Scr Mater 2000;35(7):879–84.

[4] Zhang HJ, Qiu CJ. A TiNiCu thin film micropump made by magnetron cosputtered method. Mater Trans 2006;47(3):532–5.

[5] Kong MC, Axinte D, Voice W. Challenges in using water jet machining of NiTi shape memory alloys: an analysis of

controlled-depth milling. J Mater Process Technology 2011; 211:959–71.

[6] Pradhan, M.K.(2012) " Determination of optimal parametrs with multi response characteristics of EDM by response surface methodology, grey relational analysis & principle component analysis . International journal of manufacturing & management. Vol-26, No-1/2/3/4 (2012) pp-56-86.

[7] Minitab14 (2003). Minitab User Manual Release 14. State College, PA, USA.

[8] J. L. Deng, "Introduction to grey system theory," J. Grey Syst., vol. 1, pp. 1–24, November 1989.

[9] K. L. Wen, T. C. Chang, and M. L. You, "The grey entropy and its application in weighting analysis," IEEE International Conference on Systems, Man, and Cybernetics vol. 2, pp. 1842–1844, 1998.

[10] S.K. Majhi, M.K. Pradhan, H. Soni, Application of Integrated Rsm-Grey-Entropy Analysis for Optimization of Edm Parameters, (2013) 4–9.