A Comparative Evaluation of Process Parameter Optimization of Wire Cut Electric Discharge Machining of Ti-6Al-4V Using WASPAS and Metaheuristic Methods

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ABSTRACT

Ti-6Al-4V is a very effective alloy as it is used in various field such as defense and medical. It has very high corrosion resistance and having high weight ratio. It has been a difficult material to be machined using conventional methods of machining, thus nonconventional methods were adopted for effective machining of this material as EDM and WEDM. In this investigation attempt has been made for comparative study of optimum process parameters for wire EDM process to using Multi Criteria Decision Making (MCDM) process called Weighted Aggregated Sum Product Assessment (WASPAS) method and Metaheuristic method as Multi-objective Genetic Algorithm (MOGA) for determination of optimum combination of process parameters for optimum output as maximum MRR and minimum SR. These methods have been effectively compared. The input parameters that have been taken into consideration are peak current, wire speed, pulse on time , pulse off time , wire feed and wire tension. These methods also can be used in other machining process parameter optimization problem in manufacturing as efficient methods.

Keywords
Wire EDM, Weighted Aggregated Sum Product Assessment,Genetic Algorithm, MOGA

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Introduction

Wire cut electric discharge machining is an advanced form of EDM. The electrode is used in the form of a continuously moving wire from a spool. However, there is no physical contact between the wire and the work piece. It is a very efficient process used in die and tool making industry. Several difficult to machined alloys like tungsten and titanium based, Inconel etc. are machined using Wire EDM process. The wire used is copper, brass or coated. There is a continuous conversion of electrical energy to thermal energy. Unlike other nonconventional processes, Wire EDM requires little to no further processing of the work piece as most of the obtained products are the finished parts.
Chakraborty et. al. [1] has analysed five Non Traditional Machining processes. WASPAS method has been used to explore the parametric optimization in experiments performed by rsearchers in five types of NTM processes namely ECDM, EDM, USM, LBM and WEDM. Different process parameters selection applicability and effectiveness. The WASPAS method was carried out for both single as well as multiple response optimization problems. The value of λ was varied from 0 to 1 and based on the obtained total relative significance of attributes the ranking was done. Tiwary et. al. employed micro hole machining on Ti-6Al-4V. The main objective of this experiment was to look for the optimized values of process parameters namely peak current, pulse on time, flushing pressure and dielectric type. WASPAS method was used for this purpose. A multi criteria decision model was established for high MRR, low tool wear rate, overcut and taper. The obtained results were validated experimentally. Nagaraja et. al. [3] investigated the process parameters influence on bronze-alumina MMC using Wire EDM. The main objective of this experimental work was checking the optimal cutting rate for maximum surface roughness. Pulse on time, pulse off time, wire feed rate were the input parameters. ANOVA or Analysis Of Variance and S/N ratio have been used for the analysis of the influence of process parameters on surface roughness. The obtained result was that the wire feed was the most influential of all process parameters on the response parameters. Dewangan et. al. [4] investigated the effect of input parameters on AISIP20 tool steel using EDM process. The main objective of this work was to determine from all input parameters namely pulse on time, peak current, pulse off time ,tool lift time, tool work time ,the most effective parameter using Response Surface Methodology. Rajyalakshmi et. al.[5] worked on Inconel 825 to investigate the process parameter optimization. The objective of this experiment was to obtain maximum MRR and minimum Ra. Taguchi based Orthogonal Array method was used for this purpose. Chakraborty et. al. [6] explored the applicability of MCDM approach in decision making. They used WASPAS method to solve eight manufacturing decision making problems which are cutting fluid selection, foraging condition, electroplating system, arc welding process, milling condition, industrial robot, materials machinability and electro discharge micro machining. It was found that the WASPAS method gave almost accurate rankings of the candidate alternatives in comparison to those which earlier researchers found. Reddy et. al.[7] performed the experiments on AMMNC sample of Carbon Nano Tubes (CNT) reinforced Al 506. The objective of this experiment was to evaluate optimized process parameters values i.e. pulse on time, pulse off time, peak current, flushing pressure using Taguchi Design of Experiment and maximize MRR while lowering surface roughness, Kerf Width and tool wear. De et. al. [8] did the parametric study of the sintered titanium through Wire EDM. The aim of the work was to

investigate the response parameters i.e. surface roughness, MRR, kerf width and over cut using RSM or Response Surface Methodology.

In recent day scenario the methaheuristic methods are thetrend used for optimization problems as Evolutionary algorithms. The present work is about the application of WASPAS method and metaheuristics as Genetic Algorithm their comparative study for determination of optimal set of process parameters in case of machining Ti-6Al-4V using WEDM. These process parameters are peak current (Ip), wire feed (Wf) , pulse on time (Ton) , pulse off time (Toff) and wire tension (Wt), while surface roughness (Ra) and material removal rate (MRR) are the required response parameters.

Maximum value of MRR and minimum value of surface roughness are the key deciding factors here. The work piece used here is Ti-6Al-4V (alpha-beta phase of titanium alloy). This material has high strength to low weight ratio with excellent resistance property against corrosion. It is primarily used in applications where low density and corrosion resistance material are demanded.

Methodology

Here, in this investigation brass has been used as wire in WEDM for machining of titanium based alloy. Design of experiments has been used as L9 (3 level) for assessment of interaction between four input process parameter and twooutput parameters. Weighted Aggregated Sum Product Assessment method has been used as a Multi Criteria Decision Making (MCDM) tool. Linear Rigression modelling of datas has been performed with checking the trueness of model with calculation of R2 values. After model has been finalized metaheuristic method has been performed for multi criteria decision making as multi-objective optimization problem using Multi-objective Genetic algorithm.

A. WASPAS

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

It is a combination of Weighted Product Model (WPM) and Weighted Sum Model (WSM) which are two MCDM tools. At first a decision matrix is developed as, X = [Xij]mxn ,where Xij is the performance of the ith alternative with respect to the jth criterion, m is the number of candidate alternatives and n is the number of evaluation criteria. WASPAS is very effective process of determining the parametric combinations as its a hybrid of two generalized methods used for ranking. The already conducted experimental trials are brought under consideration for this purpose. It is more efficient than the single methods since it is an aggregated method. Here, in below steps for WASPAS procedure has been stated.

i. Initialize the matrix for solving the selection problem (selection of best criteria from given attributes).

ii. Normalise the decision matrix for maximization and minimization criterions as in (1) &(2).

$$\bar{x}_{ij} = \frac{x_{ij}}{\max(x_{ij})} \quad (1)$$

$$\bar{x}_{ij} = \frac{\min(x_{ij})}{x_{ij}} \quad (2)$$

iii. Calculate total relative importance based on WSM method (3).

iv. Calculate total relative importance based on WPM method (4). Where, Wij is the weight calculated using entropy method or the analytical hierarchy process.

$$\bar{Q}_i^{(1)} = \sum_{j=1}^{n} \bar{x}_{ij} W_j \quad (3)$$

$$\bar{Q}_i^{(2)} = \prod_{j=1}^{n} (\bar{x}_{ij})^{W_j}$$

v. In order to have improved ranking accuracy and helpfulness of the decision making process, in the WASPAS method, a more general equation for total relative significance of alternatives is given by (5),

$$Q_i = \lambda \bar{Q}_i^{(1)} + (1-\lambda)\bar{Q}_i^{(2)} \quad (5)$$

where, , $0 \le \lambda \le 1$.When, $\lambda=0$, the equation transforms to WPM and for $\lambda=1$, the equation transforms to WSM.

Lastly the alternatives are ranked on the basis of the obtained Q values. The ranking is done in the descending order of the Q value i.e. the highest Q value is marked number 1, then 2 and so on. The higher the rank value, the better is the performance and the corresponds to optimum process parameter. Both single and multi response optimization problems can be dealt with this process.

B. Genetic Algorithm

Holland [9] proposed an evolutionary algorithm for global optimization for mixed integer model problems in 2001. The genetic algorithm adopts the biological evolution principle which states existence of fittest population that has been evolutional from earlier population and have strong inherited criterion for survival. Genetic algorithm uses initiation of population, encoding, evaluation, criteria checking, mutation and crossover as flow steps for its operation. In each evaluation population has been updated using random crossover and selection procedures as roulette wheel or pareto front. These unique selection strategies can be very much efficient in global optimum search strategy allowing the optimizer not to trap in local optimum points.Hence, this method is found to be excellent in productivity and exceptionally stable in hanlding variety of optimization problems in search of global optium points. The advancement in the evolutionary algorithm as MOGA has been first proposed by Deb et. al. [10] for handling multi- objective problems using variety of selection procedures. Flow chart of GA has been shown in Fig.1.

C. Mathematical Modeling

The dependency of output variables in independent input variables can be shown as mathematical linear regression model using surface response methodology. Here in this problem linear regression expression has been obtained using RSM method for each objective as MRR and SR as in (6) and (7).

y(1) = 2.834+0.523*x(1)+-0.249*x(2)-0.132*x(3)-0.140*x(4)+4.133E-04*x(1)*x(2)*x(3)*x(4) (6)

y(2) = -9.658+0.478*x(1)+0.399*x(2)+0.504x(3)+0.542*x(4)-7.294E -04*x(1)*x(2)*x(3)*x(4) (7)

Result And Discussion

TABLE I. CONTROL FACTORS AND LEVELS

Factors	*Level 1*	*Level 2*	*Level 3*
Pulse on time T_{on}	6	8	10
Pulse off time T_{off}	8	10	13
Wire tension W_t	6	8	10
Wire feed W_f	7	9	11

TABLE II. RESPONSE PARAMETERS (SR, MRR)

Exp no.	*Ton in µsec*	*Toff in µsec*	*Wt in KN*	*Wf in KN*	*MRR in mm³/Min*	*Surface roughness (Ra)*
1	6	8	6	7	3.147	2.444
2	6	10	8	9	3.049	2.859
3	6	13	10	11	3.506	3.107
4	8	8	8	11	4.265	3.519
5	8	10	10	7	4.858	2.909
6	8	13	6	9	4.02	2.983
7	10	8	10	9	6.521	2.726
8	10	10	6	11	6.421	3.201
9	10	13	8	7	5.497	3.005

TABLE III. NORMALISED DATA TABLE RANKING WITH WASPAS RESULTS

Exp no	*MRR*	*SR(Ra)*	$Q^{(1)}$	$Q^{(2)}$	*Q*	*Rank*
1	0.483	1	0.744	1.698	1.221	5
2	0.468	0.855	0.663	1.610	1.137	9
3	0.538	0.787	0.663	1.622	1.142	8
4	0.654	0.695	0.674	1.642	1.158	7
5	0.745	0.840	0.793	1.780	1.287	4
6	0.616	0.819	0.719	1.691	1.205	6
7	1.0	0.897	0.947	1.946	1.447	1
8	0.985	0.764	0.872	1.865	1.369	2
9	0.843	0.813	0.828	1.820	1.324	3

WASPAS method has been applied in this research work. Table I and Table II are levels of control parameters and the output experiment response in case of the stated process parameter optimization experiment set. The MRR is higher the better and the surface roughness is the lower the better. Therefore MRR here is the beneficial criteria whereas surface roughness is the non-beneficial criteria.The response parameter values i.e. MRR and Ra values are normalized using the formulae in step ii. Based on WSM and WPM models, the total relative importance of the ith alternative is calculated using the formulae in step iii and iv respectively. The following table 3 displays the WASPAS scores obtained for each response parameter. The value of λ has been taken to be 0.5 so to give equal weightage for both combined methods as WPM and WSM respectively. The weight Wij has been calculated using the entropy method. The obtained value of the weight is 0.494 for MRR and 0.506 for surface roughness. From the data obtained in the table 3 above it has been found that the maximum material removal rate is observed in the experiment no 1 whereas the minimum surface roughness is found in experiment no 5. But when multicriterion decision making approach is considered experiment no.7 with respective output response values 6.521 and 2.726 with inputs as Ton at 10, Toff at 8, Wt at 10 and Wf at 9 is found to be very effective as the most optimum MRR and roughness value achieved.

Fig.2 shows convergence characteristics of both objectives as MRR and SR considering maximization and minimization criteria respectively along with spread of population using MOGA. Code for Genetic Algorithm has been incorporated with pareto optimal study, run in MATLAB2018. The optimization iteration run about 812 and average spread observed to be 0.122 which implies that the above multi- objective problem converge faster without trapping in to discrete mixed integer function. The results shows highest MRR and lowest SR as 6.619 and 2.854 with inputs as Ton at 9.856, Toff at 8.283, Wt at 9.629 and Wf at 8.841.

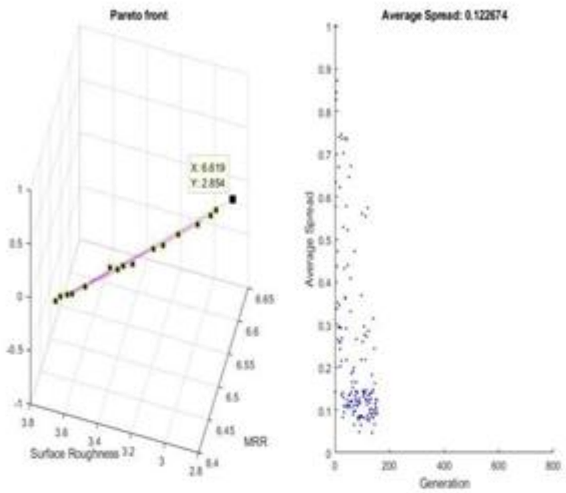

Fig.2.Convergence characteristics of MRR and SR and spread of population

Conclusion

Optimum process parameters for machining of hard material like Ti-6Al-4V have been found efficiently using WASPAS and metaheuristic method as Multi-objective Genetic Algorithm. Both the methods are found to be close affirmatives with each other. As compared in Genetic algorithm is found to be more flexible in finding optimum process parameters as here in mixed integer problem. Form the above results it also been seen that SR value found in MOGA when compared with the value of WASPAS is bit greater but when comparison is done with respect to MRR value MOGA result is far ahead of result of WASPAS. In conclusion we can say that for machining process like stated MOGA results are more effective as MRR is more important output response. In conclusion the above methods can be used for variety of multi-objective problems in manufacturing arena and constraints can be incorporated for better results in intricate optimization problems. The Metaheuristic methods are found to be more flexible handling mixed integer problem with or without constraints.

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