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Optimization of Wire Electric Discharge Machining Process Parameters Using Titanium Alloys –A Review

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Abstract- WEDM is one of the important variants of electrical discharge machining (EDM) which uses the thermal energy generated between the electrodes for machining the electrically conducive materials. This method has been successfully implemented in common materials like aluminum, stainless steel etc., But its application in super alloys like Ti6Al4V is still under investigations. This paper reviews the research work carried out for optimization of WEDM process on titanium and its alloys. It reports on the WEDM research involving the optimization of process parameters surveying the influence of the various factors affecting the machining performance and productivity.

1. INTRODUCTION

Accompanying the development of mechanical industry, the demands for alloy materials having high hardness, toughness and impact resistance are increasing. Nevertheless, such materials are difficult to be machined by traditional machining methods. Hence, non-traditional machining methods including electrochemical machining, ultrasonic machining, electrical discharging machine (EDM) etc. are applied to machine such difficult to machine materials. WEDM process with a thin wire as an electrode transforms electrical energy to thermal energy for cutting materials. With this process, alloy steel, conductive ceramics and aerospace materials can be machined irrespective to their hardness and toughness. Furthermore, WEDM is capable of producing a fine, precise, corrosion and wear resistant surface.The outstanding properties of titanium such as high strength, high strength to weight ratio, high toughness, corrosion resistance and long standing are the main cause of widely use of titanium and its alloys. Machining of titanium in the minimum time and with maximum precision is a considerable issue in all application fields of titanium such as biomedical applications, automobile, aerospace, chemical field, electronic, gas, food and especially biomedical industries. Over the past three decades, application of titanium in medical and biomedical devices has expanded due to development of new processing methods such as computer-aided machining and Wire Electrical Discharge Machining (WEDM). WEDM process is a non-traditional machining method that has provided an effective solution to machine difficult-to-machine materials. The quality of engineering parts and components is measured by surface roughness that is one of the machining factors. The huge heat generated during WEDM leads to the microstructure and material composition change and a layer of oxide produced on the machined material surface. Therefore, machining titanium with a high quality, smooth surface and high accuracy is a purpose for most of the industries and researchers

2. METHODS OF MULTI-OPTIMIZATION

There are different methods developed by many researchers for optimizing multiple parameters in processing on materials. The different methods used for multi-optimization are as follows :

- Statistical Regression Technique

The data collected through experiments usually exhibits a significant degree of error or as “noise”. In such a case there is no need to intersect every point as the individual data points, may be incorrect. Rather the curve is designed to allow the pattern of points taken in group. This approach is known as statistical regression technique for investigating functional relationship between output and input decision variables of a process and may be useful for manufacturing process data description, parameter estimation and control

- Taguchi Robust Design method

Taguchi methods have been used widely in engineering analysis to optimize performance characteristics by means of setting of design parameters. Taguchi method is combination of mathematical and statistical techniques used in an empirical study. It uses fewer experiments required in order to study different level of all input parameters, and filtering out few effects due to statistical variations. Taguchi method can also determine the experimental conditions having the least variability as the optimum condition.

- Response Surface methodology

Response surface methodology (RSM) is a collection of statistical and mathematical methods that are useful for modeling and optimization of the engineering science problems. In this technique the main objective is to optimize the responses that are influenced by various input process parameters.RSM also quantifies the relation between controlled input parameters and the obtained responses. In modeling and optimization of manufacturing processes using RSM, the sufficient data is collected through designed experimentation. In general a second order regression model is developed because of first order models often give lack-of-fit.

- Taguchi fuzzy-Based approach

Taguchi fuzzy-Based approach is the fuzzy logic analysis coupled with Taguchi methods for optimization in case of multiple performance characteristics. In Taguchi method, for single process response, the optimum level of process parameters is the level having the highest S/N ratio. However, optimization of multiple responses is not as straightforward as that of optimization of a single process response. A higher S/N ratio for one process response may correspond to a lower S/N ratio for another process response. As a result, an overall evaluation of S/N ratios is required for the optimization of multiprocess response. Fuzzy logic is to develop fuzzy reasoning of multiple performance characteristics.

- Gray Relational Analysis (GRA)

In WEDM, the quality and integrity of machined surfaces are dependent on different process parameter combinations. .These process parameter significantly affect the performance measures such as surface roughness, metal removal rate (MRR), dimensional deviation and kerf width. .In order to minimize these machining problems, scientific method based on Taguchi designed of experiments is used. However Taguchi method has been designed to optimize single performance characteristics and is not appropriate for multiple performance optimization. To solve such kind of problem, grey relational analysis (GRA) is necessary. Neural network and Genetic algorithm are also other optimization methods.

3. MECHANISM OF MATERIAL REMOVAL IN WEDM PROCESS

The mechanism of metal removal in wire electrical discharge machining mainly involves the removal of material due to melting and vaporization caused by the electric spark discharge generated by a pulsating direct current power supply between the electrodes. In WEDM, negative electrode is a continuously moving wire and the positive electrode is the work piece. The sparks will generate between two closely spaced electrodes under the influence of dielectric liquid. Water is used as dielectric in WEDM, because of its low viscosity and rapid cooling rate.

4. ADVANTAGES OF WEDM PROCESS

There is no direct contact between the work piece and the wire, eliminating the mechanical stresses during machining. WEDM process can be applied to all electrically conducting metals and alloys irrespective of their melting points, hardness, toughness or brittleness. Users can run their work pieces over night or over the weekend unattended.

5. DISADVANTAGES OF WEDM PROCESS

High capital cost is required for WEDM process) There is a problem regarding the formation of recast layer. WEDM process exhibits very slow cutting rate. It is not applicable to very large work piece.

6. APPLICATIONS OF WEDM PROCESS

The present application of WEDM process includes automotive, aerospace, mould, tool and die making industries. WEDM applications can also be found in the medical, optical, dental, jewellery industries, automotive, aerospace and R& D areas. The machine's ability to operate unattended for hours or even days further increases the problem.

7. Selection of WEDM Parameters

A. Process Parameters

- Pulse on time and pulse off time

Electric discharge machining must occur (ON time) and stop (OFF time) alternately during machining. During the ON time, the voltage is applied to the gap between the work piece and the electrode (wire), while no voltage is placed during the OFF time. Consequently, electric discharge occurs only for the duration of the ON time. To have a long duration of the electric discharge , it may be possible to select the great value for the ON time, however it may cause short circuit to occur, resulting in wire breakage. To avoid this, the OFF time must be inserted.

- Peak current and gap voltage

The peak current is basically a most important machining parameter in WEDM. It is the amount of power used in WEDM and measures in unit of amperage. During each pulse on time, the current increases until it reaches a preset level, which is expressed as peak current. In both the sinking and WEDM processes, the maximum amount of amperage is governed by the surface area of cut. Gap voltage or open circuit voltage specifies the supply voltage to be placed on the gap. The greater this value is, the greater the electric discharge energy becomes

- Servo voltage and servo feed rate

Parameter servo voltage (SV) is used for controlling advances and retracts of the wire. During machining, the mean machining voltage varies depending on the state of machining between the work piece and the electrode. SV established the reference voltage for controlling advances and retracts of the wire. If the mean machining voltage is higher than the set voltage level, the wire advances, and if it is lower, the wire retracts 9to be precise, the work table advances or retracts instead of wire).

- Dielectric flow rate

Electro discharge can occur in the air, however, it is not stable and can not be used for rough cut machining. To obtain stable electric discharge, dielectric fluid is required. Within the dielectric fluid, electric discharge machining can be stabilized with efficient cooling and chip removal. The de-ionised water is typically used as a dielectric in WEDM.

- Wire speed or wire feed

Wire speed is another important parameter in WEDM that show the speed of the wire in WEDM. As the wire speed increases the wire consumption and in result the cost of machining will increase the cost of machining, while low wire speed can cause wire breakage in high cutting speed.

- Wire tension

Wire tension is the factor that can control the tension of wire in WEDM. If the wire tension is high enough the wire stays straight otherwise wire drags behind.

- Wire type

The key physical properties of EDM wires include, Conductivity. A high conductivity rating is important because, at least theoretically, it means the wire can carry more current, which equates to a hotter spark and increased cutting speed. Tensile strength, elongation, straightness, flush ability and cleanliness are other important factors.

- Different wire materials

Copper, Brass, Coated Wires and Fine Wires are used generally wire materials in WEDM. Excellent conductivity is very important factor but other factors such as low tensile strength, high melting point, low vapor pressure severely limit the potential.

B. Process Measures

(i) Material Removal Rate (ii) Surface Roughness (iii) Gap Current (iv) Dimensional Deviation

WEDM responses are greatly influenced by Electrode parameters (Wire material, wire size, wire feed rate and wire tension), Electrical parameters (Pulse on time,pulse off time, servo feed, peak current, gap voltage , spark gap set voltage), Non electrical parameters (Dieelectric flow rate andconductivity of die electric) and Work piece (Material and height).

8. LITERATURE SEARCH ON WEDM OF TITANIUM ALLOYS

The machining of titanium and its alloys is generally cumbersome owing to several inherent properties of the material. Titanium is very chemically reactive and therefore has a tendency to weld to the cutting tool during machining thus leading to premature tool failure [1].DanialGhodsiyeh et al.[2,3] studied the effect of machining parameters including pulse on time, pulse off time, and peak current on surface roughness, sparking gap and material removal rate of titanium (Ti6Al4V). Stastical optimization model (a central composite design coupled with response surface methodology overcomes the limitations of classical methods and was successfully employed to obtain the optimum processing conditions while the interactions between process variables were demonstrated. Taguchi method was also employed. Vamsi Krishna Pasam et al. [4] worked for the optimization of surface finish in Ti6Al4V using Taguchi parameter design method. Selection of optimum machining parameter combinations for obtaining higher accuracy is a challenging task in WEDM due to presence of large number of process variables and complex stochastic process mechanisms. The behavior of eight control parameters such as ignition pulse current, Short pulse duration, Time between two pulses, Servo speed, Servo Reference Voltage, Ignition pressure, Wire Speed and Wire tension on surface finish was studied using Taguchi parameter design A mathematical model is developed by means of linear regression analysis to establish relation between control parameters and surface finish as process response. An attempt is made to optimize the surface Roughness prediction model using Genetic Algorithm (GA). V. Vaseekaran et al. [5] reported the mechanisms associated with the spark erosion process in TiB_2 and zinc . The study is based on the investigations on the effects that the tool electrode geometry, input energy and electrode polarity have on the main parameters governing the capacitor process. Single capacitor discharge experiments using a copper pin type tool electrode on plate-type work piece electrodes (TiB_2 andZinc) are used. Kuriachen Basil et al.[6] studied to evaluate the machine performance of grade-5 titanium alloy in WEDM. Design of experiments was adopted in this study to determine the optimum condition of machining parameters and the significance of each parameter on the performance of machining characteristics. Although eighteen experiment trial runs were performed using randomized parameters obtained by design expert software. The mathematical model was also established to predict the value of response parameters. Anish Kumar et al. [7,8] developed the quadratic models for machining rate, surface roughness,dimensional deviation and wire wear ratio to correlate the dominant machining parameters: pulse on time, pulse off time, peak current, spark gap voltage, wire feed and wire tension in the WEDM process of pure titanium (grade 2). The experimental plan of the Box- Behnken based on the RSM has been applied to perform the experimental work. They also studied the effect of six input parameters on wire breakage frequency and the surface integrity of wear out wire during machining of pure titanium. Wire rupturing was observed at higher values of peak current and spark frequency. The wire electrode surface exhibited formation of craters and the residuals of copper, carbon, oxyzen and titanium debris adhered to it. This was concluded to be due to the melting and re-solidification of the titanium and brass wire electrode after WEDM. S.Sarkar et al. [9,10] presented an approach to select the optimum cutting condition with an appropriate wire offset in order to get the desired roughness and dimensional accuracy for machining of y-titanium aluminide alloy. The process has been modeled using additive model in order to predict the response parameters such as cutting speed ,,surface roughness and dimensional deviation. Aniza Alias et al. [11] attempted to determine the important machining parameters for performance of WEDM viz. kerf width, Material removal rate and surface roughness. The main goal was the maximum material remova rate with minimum kerf and surface roughness in setting the machining parameters. Hseighetal. [12] investigated WEDM characteristics of TiNiX (X=Zr and Cr) ternary shape memory alloys. It was that surface roughness of machined TiNiX alloys increased with growing pulse time. The hardness of each specimen was reported 875 and 807 HV for TiNiZr and TiNiCr alloys respectively.

9. CONCLUSIONS

The machining of titanium and its alloys is generally cumbersome owing to several inherent properties of the material . Machining characteristics of titanium/titanium alloys have been discussed based on a survey of literature. Besides these, multi optimization methods, mechanism of material removal rate, advantages, disadvantages and application of the WEDM process have also been included in the paper.

The ultimate goal of the WEDM process is to achieve an accurate and efficient machining performance. Understanding the interrelationship between the various factors affecting the process and identifying the optimal machining condition from the infinite number of combinations are also outlined.

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