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A Review on the Machining of Titanium Alloys using WEDM

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Abstract: There is a swift growth of high strength temperature resistant (HSTR) alloys such as Nitra-alloy, Waspa-alloy, Titanium-alloy, Inconal, Die-cast steel etc. Since, the properties of these alloy materials are high in hardness, toughness, and impact strength and temperature resistant, therefore, the machining of these materials by conservative methods is really complicated. The unconventional machining processes are most excellent matched to machine such alloys. This article presents, a comprehensive survey of various research works addressing the machining of HSTR alloys through wire electric discharge machining. Being a very complex machining process and having a large number of control parameters which affect the important response parameters like MRR, surface roughness, geometry etc, many computation tools have been implemented to optimize the process, and expert systems are developed for future predictions. Thus, the present study is an attempt to give future directions and a comprehensive update data on WEDM of HSTR alloys.

Keywords: Titanium Alloys; WEDM; Literature Review; Machining

I. INTRODUCTION

WEDM is an indispensible machining process which is used to machine complex geometric shapes where high accuracy and great surface finish is required. Because of its higher process capability and productivity, WEDM can easily machine complex parts and precision components which are difficult to be machined by conventional machining process [1].

In this operation, the material removal occurs from the electrically conductive material by initiation of rapid and repetitive spark discharge between the gap of the work and tool electrode connected in an electrical circuit. There is no relative contact between the tool and the work piece. The electrode is immersed in a liquid dielectric medium. These electric discharges melt and vaporize minute amounts of work material, which are then ejected and flushed away by the dielectric. WEDM finds extensive use in areas such as tool and die making, automobile, aerospace, nuclear, spacecrafts, marine automobile, gas-turbine engine, military ballistic, computer and electronics industries, etc [2]. Titanium alloys on the other hand are advanced materials which find use in the multi-disciplinary armor, nuclear, chemical vessels, sports and medical applications. Having properties such as high hardness, toughness, impact strength and temperature resistant, the machining of high strength alloys by conventional methods is difficult and tiresome. Among the non-conventional machining processes, WEDM is an apt process to machine such alloys [1-3, 18]

A. ***Process Details of WEDM***

WEDM is a unique kind of electric discharge machining which works on materials using a wire of small diameter as a cutting tool. The working a principle of wire cut electric discharge machining is same as that of electric discharge machining and the process details of WEDM are almost similar to EDM with little difference that the tool used in WEDM process is a small diameter wire as the electrode to cut narrow kerf in the work piece while in a EDM there is no use of wire as a tool. The wire is constantly feed between a supply spoil and wire collector, during the cutting operation. This constant feed of wire makes the machined geometry numb to bend of tool due to its erosion. Wires are generally made of brass, copper, tungsten or any added suitable materials. Normally the diameter of the wire varies from 0.076 to 0.30 mm. Wire diameters are depends on the width of kerf [1].

B. *Mechanism for Tool Feeding*

These are two types of movements; first is continuous feed from wire supply spool to wire collector. Second is movement of the whole wire feeding system, and wire along the kerf to be cut into the workpiece. These movements are brilliant with high accuracy and pre-determined speed with the applying of advanced numerical control systems [1, 18].

C. *Spray Mechanism and Fluid (Dielectric)*

Similar to the EDM process, dielectric fluid is constantly sprayed toward the machining zone. Nozzles are used to spray the fluid directed at the tool work interface or workpiece is flooded in the dielectric fluid container as shown in figure 1.

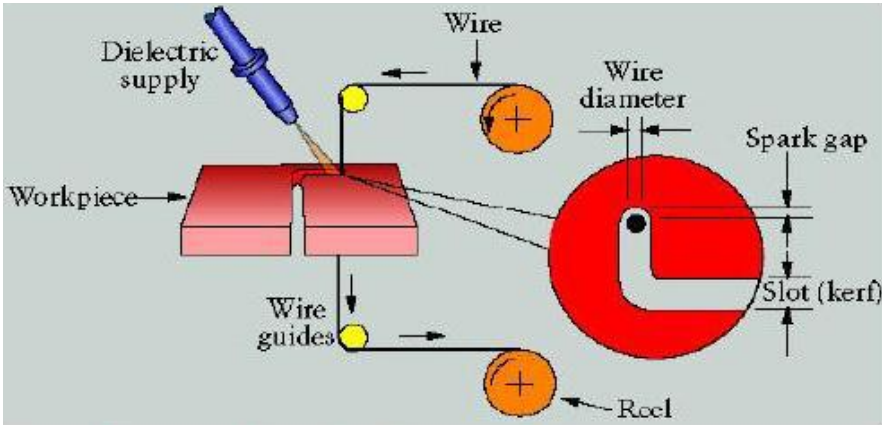

Figure 1: Dielectric Fluid and Spray Mechanism [*http://www.engineersedge.com/edm.shtml*]

D. *Machining Characteristics of Titanium Alloys* [1, 18]

1. Titanium is a strong and light metal and stronger than common, low-carbon steels, but it is 45% lighter. Moreover, Titanium is twice as strong as weak Aluminum alloys but only 60% heavier.

2. Titanium and its alloys are poor thermal conductors that results in the deliberate dissipation of heat at the same time as machining Titanium and the majority of heat is intense on the tootl face and cutting edge.

3. The alloying tendency or chemical reactivity of Titanium alloys with the cutting tool material is strong at tool operation temperatures. This causes galling, welding, and smearing, along with rapid wear or cutting tool failure.

4. Titanium alloys show thermal plastic volatility that leads to only one of its kind individuality of chip formation during machining. The shear strains in the chip are not consistent; rather, they are limited to a small area in a thin band that forms notched chips.

5. The contact length between the chip and the tool is extremely short (less than one-third the contact length of steel with the same feed rate and depth of cut). This implies that the high cutting temperature and the high stress are simultaneously concentrated near the cutting edge (within 0.5 mm).

6. Notched chips produce fluctuations in the cutting force and this situation is more promoted when α–β alloys are machined. The force of vibration, with the high temperature, exerts a micro-fatigue loading on the cutting tool, which is believed to be incompletely accountable for strict flank wears.

7. Titanium is not easily corroded by sea water, and thus is used in propeller shafts, rigging and other parts of boats that are exposed to sea water.

8. The machining of titanium and its alloys is usually awkward due to various intrinsic properties. It is highly chemically swift and it has a tendency to solder to the cutting tool during machining which leads to early failure of the tools [1, 18].

II. LITERATURE SURVEY

This section discusses various contributions on machining of Titanium alloys using WEDM. Basil et al [4] conducted a series of experiments 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. Sarkar et al [5] made an effort to optimize the process parameters of the Wire electrical discharge machining of γ-Titanium Aluminide through ANN (Feed forward back propagation neural network model). The process is carried out with Electra Super Cut 734 series200 CNC Wire cut EDM machine. The process parameters were pulse on time, pulse off time, peak current, servo reference voltage, wire tension, dielectric flow rate and response parameters were cutting speed, surface roughness and wire off set. By using feed forward 6-15-3 BPNN, WEDM process model was developed. That ANN model was used to predict the process performance for all possible combinations of 15625. Out of 15625, 27 optimum combinations were selected and act as technological guidelines for effective machining of the alloy. From this process, it was concluded that the surface quality decreases as the cutting speed increases and they vary almost linearly up to a surface roughness value of 2.44 μm and a cutting speed of 2065 mm/min. beyond this value of cutting speed, surface roughness deteriorates drastically.

Hsieh et al [6] 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. Kuriakose et al [7] carried out experiments on Ti6Al4V with Robofil 310, 5-Axis CNC WEDM as machine tool. The process parameters of the WEDM process were time between two pulses, pulse duration, servo voltage, servo speed variation, wire speed, wire tension and injection pressure. The experiments were planned as per Taguchi's L18 orthogonal array. The machining was performed with zinc coated and uncoated brass wire of 0.25mm diameter. Taguchi's and ANOVA methods have been effectively employed to find out the influence of process parameters. For uniform surface characteristics the coated wires were preferred over than the uncoated wires. The time between two pulses was the most sensitive parameter that influences the formation of layer consisting of mixture of layers.

Gokler et al [8] conducted experiments on Sodic Mark XI A500 EDW WEDM as machine tool and 1040, 2379 and 2378 steel as work piece materials in order to investigate the effect of cutting and offset parameters on surface roughness in WEDM process. From the results it was concluded that, the offset parameters does not affect the surface roughness and same result with cutting parameters .If the thickness of the work piece increases, the average feed rate decreases. Hewidy et al [9] has been investigated the WEDM performance on Inconel 601 by using response surface methodology (RSM). They have confirmed that surface roughness increase with the increase of peak current and decrease with increase of duty factor and wire tension. Mahapatra and Patnaik [10] used coated wire electrode to investigate WEDM machining performance. Coated brass wire can perform at higher cutting speed as compared to brass wire electrode. Coated brass wire can also produce exceptional surface finish. Ghodsiyeh et al [11] 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.

Pasam et al [12] 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 behaviour 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. Vaseekaran et al [13] reported the mechanisms associated with the spark erosion process in TiB2 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 (TiB2 and Zinc) are used.

Liao et al [14] studied the effect of specific discharge energy on WEDM characteristics of Ti-6Al-4V and Inconel 718. A quantitative relation between machining characteristics and machining parameters was derived. It was observed that two most significant factors affecting the discharge energy (η) are discharge-on time (pulse on time) and servo voltage. Moreover, discharge-on time and work piece height have a significant effect on machined groove width. Rao et al [15] conducted experiments on Graphite work piece with ELCUT 234CNC WEDM. The process parameters were discharge current, Gap Voltage, wire tension, wire speed and output responses were cutting speed, spark gap and MRR. The thickness of the work piece varies from 5mm to 80mm.From the results it was concluded that with increase in thickness, the required current also increases. As the thickness of the work piece increases, the cutting speed decreases rapidly and spark gap increases. But beyond 60 mm thickness, the rate of variation of spark gap was low. The MRR was increased with increase in thickness due to the increase in cutting speed and spark gap.

Garg et al [16] studied the effects of various process parameters of WEDM like pulse on time (TON), pulse off time (TOFF), gap voltage and conducted experiments on Graphite work piece with ELCUT 234CNC WEDM. The process parameters were discharge current, Gap Voltage, wire tension, wire speed and output responses were cutting speed, spark gap and MRR. The thickness of the work piece varies from 5mm to 80mm.From the results it was concluded that with increase in thickness, the required current also increases. As the thickness of the work piece increases, the cutting speed decreases rapidly and spark gap increases. But beyond 60 mm thickness, the rate of variation of spark gap was low. The MRR was increased with increase in thickness due to the increase in cutting speed and spark gap. Guven et al [17] carried out experimental studies on AISI 4340 steel as work piece and ACUTEX WEDM as machine tool with CuZn37 sun cut brass wire with 0.25mm diameter. They used two neural network techniques i.e. BPN and GRNN to determine and compare the parameters of WEDM with the features of surface roughness .From the results it was concluded that BPN and GRNN's can model is the WEDM with reasonable accuracy.

Singh and Khanna [18] investigated the outcome of parameters on cutting rate of cryogenic-treated D-3 steel in WEDM. They come across that cutting rate decreases with increases in pulse width, time between two pulses and servo voltage. Yang et al [19] studied the variations in MRR and quality performance of roughness average and corner deviation depending on parameters of WEDM process in relation to the cutting of pure Tungsten profiles. They proposed a hybrid method including back-propagation neural network (BPNN) and RSM integrated simulated annealing algorithm in order to determine an optimal parameter setting. In addition, the field-emission scanning electron microscope images illustrate that after the WEDM process, numerous built-edge layers existed on the finishing surface. The optimized result of BPNN with integrated simulated annealing algorithm was compared with RSM approach. Comparisons demonstrated that RSM and BPNN/ simulated annealing algorithm are effectual tools for the optimization of parameters in WEDM process.

Spedding and Wang [20] have arrived at the optimal combination of parameters for maximum cutting speed, keeping the surface roughness and waviness within the required limits, but the optimization method is not specified. Scott et al. [21] proposed a factorial design model to measure the process performance as a function of different control setting. The process was further optimized by introducing the concept of a non-dominated point. Tarang et al [22] developed a feed-forward neural network to associate cutting parameters with cutting performances. A simulated annealing (SA) algorithm was then applied to the neural network to solve for the optimal cutting parameters.

Ramakrishnan and Karunamoorthy [23] used multi response optimization method using Taguchi's robust design approach for WEDM. Each experiment had been performed under different cutting conditions of pulse on time, wire tension, delay time, wire feed speed and ignition current intensity. Three responses namely material removal rate, surface roughness and wire wear ratio had been considered for each approach. It was observed that the Taguchi's parameter design is a simple, systematic, reliable and more efficient tool for optimization of the machining parameters. It was indentified that the pulse on time and ignition current had influenced more than the other parameters. Kanlayasiri et al [24] used a Sodic A320 WEDM with ire electrode of 0.25mm diameter and DC53 was used as work piece material. He studied the effect of WEDM machining parameters pulse on time, pulse off time, pulse peak current, wire tension and surface roughness as response. The ANOVA technique was applied to find out the effect of process parameters on surface roughness. The ANOVA results were examined through residual analysis. Results from ANOVA showed that the surface roughness increased with the increase of pulse on time and pulse peak current.

III. CONCLUSIONS

After the comprehensive study of literature, it has been observed that there exists a plethora of space for research under WEDM some of which are as follows:

- Inadequate work has been done on WEDM of pure titanium (grade-2). The pure titanium is widely used for Heat Exchangers Sea, Reactor Vessels and Water Piping.
- The machinability of titanium for WEDM desires to be studied. Because, recast layer is a ordinary occurrence in EDM that cause some problems. Various materials melt and re-solidify on the base materials, giving rise to surface coating in which the properties are different from those of the original material.
- Very small effort has been reported on the subject of the feasibility of using an unusual machining process such as WEDM for machining of titanium. There is a serious necessitate for optimization of process parameters using WEDM.
- There exists space for research of the Hybridization process in this field. Another area of research can be several novel materials in the vein of metal matrix composite.

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