Comparative Study of Electric Discharge Machining, Electrical Discharge Drilling and Electrical Discharge Diamond Drilling of Nimonic 75

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Abstract. Due to wide range of applicability of hard and difficult-to-machine materials like super-alloys (Ti-alloys, Inconel, and Hastelloy etc), advanced ceramics, composite materials, and high technical characteristics of above-mentioned materials, suitable advanced machining processes are conducted. EDM is one of the most popular advanced machining processes. But the EDM process has low metal removal rate (MRR) so EDD is another machining process as it has relatively higher MRR as compared to EDM. Here electric discharge diamond drilling (EDDD), a hybrid-EDM process comes into the picture in order to improve the machining performance characteristics. The present research aimed to compare the process performance in electrical discharge cutting, drilling and diamond abrasive drilling. The effects of process parameters such as peak current (I), pulse-on time (Ton), and pulse-off time (Toff) were studied on metal removal rate (MRR) and tool wear rate (TWR) in electrical discharge diamond drilling of Nimonic 75.

1. Introduction

Advanced engineering materials such as super-alloys, titanium alloys, sialon, advance composites, high strength temperature resistant materials (HSTR) have emerged recently, which added pace in aircraft industries and related technology. These materials possess properties like high hardness, fatigue strength, toughness, corrosion resistance, creep resistance and poor thermal diffusivity etc. However, these properties impose challenges to traditional machining processes in terms of production of high surface roughness, frequent cutting tool failure, inaccurate geometrical dimension and production of complex features. To meet these challenges, unconventional machining processes (UMPs) have come into existence. Theses UMPs are electrical discharge machining process (EDM),
electric discharge drilling (EDD) electrochemical machining (ECM), jet machining process (JMPs), ultrasonic machining processes (USM) and so on. Recently, a new drift has been introduced to merge the features of different conventional and unconventional machining processes. Such machining processes are called as hybrid machining processes (HMPs). HMPs are developed to take advantage of each of the constituent machining processes and diminish the disadvantages of each constituent process. It has been observed that, hybrid machining process improves the machining performances, increases the capabilities of the constituent processes, and widen the area of application of the constituent processes.

In the EDM process, the constant tool is utilized for making a blind hole and EDM drilling, a rotating tool electrode is used for making a blind hole.

The metal bonded diamond abrasive tool is used for making the blind hole is known as electric discharge diamond drilling (EDDD). Some author makes an approach in these directions such as Shu et al. [1] drilled holes in mild steel HPM50 and WC P20 materials.

It was found that the Ra value of the surface produced by EDDD is improved. They used a tool electrode made of fine copper-bonded SiC abrasive in EDDD process. Effect of pulse current, duty factor, grain size and wheel speed were estimated on surface roughness and wear rate based on an experimental investigation in EDDD. Surface roughness and wear rate of HSS has been predicted and optimized using an artificial neural network [2]. EDDG is also reported on Al-SiC metal matrix composite using an artificial neural network. The effect of influencing independent variables like duty factors, Ton, abrasive wheel speed (AWS) and current on SS and metal removal rate (MRR) have been analyzed during EDDG. Responses were optimized up to the adequate level such as a higher value of AWS and lower value of Ton, duty factor (DF) and pulse current, [3]. The effects of Ton, Toff and dielectric flux density were also examined over the temperature distribution during the EDM process [4]. Surface integrity of D2 steels was investigated in EDDSG process by using scanning electron microscopy (SEM) test. An EDDSG experiment reviles that by increasing peak current, MRR increases. If the rotational speed is increasing, it leads to increase the mechanical abrasion [5].

Optimization of SR and MRR is already reported on HSS under EDDSG having few important inputs [6]. Experimental investigations had been done of EDDG on Al–10 wt.% IC Composite [7]. The workpiece has been cut with the help of EDDCG using metal bonded diamond assisted grinding wheel. Due to the influence of dielectric, work surface and the diamond assisted wheel is separated. Abrasion takes place due to sparking and influence of diamond grains having inter-electrode gap-width (gw) which is less than protrusion height (P_h) [8].

It is evident that EDDCG (discharge diamond cutoff grinding) process is applied for material removal on titanium alloy (Ti-Al-Mo-V). MRR and SR (surface roughness) are optimized for the same using response surface experimental design [9]. EDDCG process was also applied on metal matrix nano-composite to estimate the effects of rotational speed, gap current, Ton and DF on surface roughness (Ra) and material removal rate (MRR) [10]. Theoretical studies of WEDM critical parameters and their effect on Monel alloy have been evaluated for the SR and MRR. In the present study, SR and MRR were selected as response parameters for the independent variables such as air inlet pressure, pulse off time, water flow rate, pulse-on time and wire feed, were taken as input parameters [11]. To estimate the effects of individual independent parameters on SR and MRR, one factor at a time approach is being adapted during EDDFSG (electrical discharge diamond face surface grinding) hybrid process on metal matrix composite (MMC). Recast layer formation on the machined surface is also evaluated by using Scanning Electron Microscopy (SEM). This process was optimized for higher MRR with good surface finish and hard recast layer [12]. A magnetic aided electric discharge machining of Aluminium-based MMC was performed in order to improve its process performance. Outcome reviles that an improvement of approx. 12% in MRR and reduction in recast layer thickness at high spark and magnetic energy [13].
The electric discharge diamond grinding (EDDG) has been used in different modes of operation like surface grinding and cut-off grinding for machining of difficult-to-cut materials and found an improved response of material removal rate [14-15]. A. Okade et al. [16] Proposed a method for curved hole EDM drilling performance improvement using a suspended ball electrode by workpiece vibration. The results have shown that this method really improved curve hole EDM drilling by workpiece vibration. Sagar U. Sapatkal et al [17] studied optimization of micro EDM drilling of Ti6Al4V by using copper tungsten tool electrode and applied response surface methodology (RSM) based on the central composite design (CCD). Pulse-on time (Ton), discharge voltage (V_d), capacitance (C) and electrode rotation speed (RPM) were considered as input process parameters whereas material removal rate (MRR), side gap width, and taper ratio as response parameters. The results show that for MRR, discharge voltage, capacitance and electrode rotation speed influenced the most. Similarly, side gap width was found influenced by Ton, C, RPM. In contrast, the taper ratio found influenced by Ton, C. Grzegorz et al. [18] studied the influence of the length of the tool electrode on the performance of micro-EDM. They derived characteristics of micro-drilling in stainless steel samples depending on the length of the tool electrode. MRR, tool wear ratio, machining accuracy were the main concerned taken by authors. M Klinev et al. [19] performed EDM drilling on non-conductive materials in deionized water. During the experiment, they applied an assisting conductive layer to the surface of the workpiece to start the discharge process. It was found that ZrO2 was able to machine easily in deionized water. By this method, a hole up to 1.5 mm depth in ceramic material can be drilled in the presence of deionized water. Raju et al. [20] studied the multi-performance operation of micro-EDM drilling of Inconel 600 alloy using grey relational analysis (GRA). The EDM feed rate, voltage (V), capacitance (C), pulse-on time (Ton), pulse-off time (Toff) were considered as input parameters whereas MRR, taper angle, overcut, diametric variance at entry and exit of micro-hole were considered as performance measures. The results show that capacitance (C) influenced the most to taper angle followed by voltage and feed rate.

From the literature review, we found that few researchers are striving to improve the machinability of such advanced materials using unconventional and hybrid machining technique. The present study aimed to create a blind hole in Nimonic alloy using different machining processes such as EDDD, EDD and EDM. It can be said that the EDDD is one of the hybrid techniques which combine diamond drilling (DD) and EDM, the EDDD process as shown in Fig.1. In EDDD process, materials remove takes place from the surface by simultaneous influence of diamond grains, continuous-discrete electrical sparks resulting mechanical abrasion and electrical sparks erosion, respectively. A metal bonded diamond abrasive rotating tool electrode has been implemented to get adequate metal removal through EDDD process in Nimonic alloy (alloy of nickel-chromium having good corrosion and heat resistance). EDD process contents rotating cylindrical drills inbuilt with EDM set up to produce a hole in the workpiece material. Through the EDM process tool with zero speed is utilized for making the hole. In this research, authors performed the comparative study among these processes EDDD, EDD and EDM based on one factor at a time (OFAT) approach. The most important critical drilling parameters like peak current, pulse-on time and pulse-off time are considered as input factors. The effect of process parameters are analyzed on material removal rate (MRR) and tool wear rate (TWR) to compare the process performances through various ways. The results show that the value of MRR is higher in EDDD as compared to EDD and EDM whereas TWR is lowest in case of EDDD, compared to EDD and EDM respectively.

2. Materials and methods
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**Figure 1.** Electrical discharge diamond drilling (EDDD) set up

**Figure 2.** Diagram of metal-bonded EDDD tool
3. Results and discussion

Figure 3. Effect of peak current (I) on MRR  Figure 4. Effect of peak current (I) on TWR

The present graph of Fig. 3 is representing that comparatively high material removal takes place in EDDD with compare to EDD and EDM process. It is evident that mechanical abrasion type metal removal is also an important consideration along with thermo-physical MRR due to which more amount of metal removal reported from workpiece in EDDD than others. On the other hand, TWR is also reported slightly higher than EDD and EDM, which is not favourable for the industry as Fig. 4. Instead of using the die-sinking EDM, WEDM may be set up used in EDDD which TWR does not matter at all.

It is also very clear from Fig. 3 to Fig. 6 that MRR and TWR both are increased by increasing peak current and Ton during every process but its values are comparatively high for EDDD due to mechanical abrasion and thermo-physical means of material depletion from work and tool materials.

Figure 5. Effect of pulse-on time (T_{on}) on MRR  Figure 6. Effect of pulse-on time (T_{on}) on TWR
From Fig. 7 & Fig. 8, MRR and TWR found decreases with an increase in pulse off time (Toff) and increases with increasing pulse-on time (Ton). The optimal value of Ton and Toff may be selected for these particular applications.

As per the comparative study of electrical discharge cutting, drilling and diamond drilling process on Nimonic 75, it is evident that EDDD is most adaptive hybrid drilling technique. EDDD exhibits comparatively very high MRR and TWR at high peak current, pulse on time and high drill speed. Responses may be further optimized to improve the surface integrity of machined components as well as the process performances.

3.1. Scanning electron microscopy (SEM) analysis

The micrographs of the surface of three selected samples have been taken using scanning electron microscope (SEM) and which are shown in Fig. 9(a), (b) & (c) respectively. In order to make a difference in surface morphology of all these three samples which are machined by EDM, EDD and EDDD. From Fig. 9 (a), it can be seen that more amount of recast layers in the sample has deposited on the machined surface.

**Figure 7.** Effect of pulse-off time (Toff) on MRR

**Figure 8.** Effect of pulse-off time (Toff) on TWR

**Figure 9.** SEM Images of surface for sample machined with a) EDM at I=8A, Ton=150µs, Toff=75µs and DS=0 RPM  b) EDD at I= 8A, Ton=150µs, Toff=75µs and DS=825 RPM  c) EDDD at I= 8A, Ton=150µs, Toff=75µs and DS=825 RPM
Table 1: Comparison of response parameters among EDM, EDD and EDDD

| Response parameters | EDM      | EDD      | EDDD     |
|---------------------|----------|----------|----------|
|                     | Min      | Max      | Min      | Max      | Min      | Max      |
| MRR (gm/min.)       | 0.0014   | 0.0074   | 0.0015   | 0.046    | 0.0081   | 0.662    |
| TWR (gm/min.)       | 0.0013   | 0.0016   | 0.0048   | 0.031    | 0.0455   | 0.600    |

4. Conclusion

Based on the above experimental results, the following conclusion is drawn:

i) The performance of EDDD process has found quite better than the EDD and EDM. EDDD process found to be the best process because of simultaneously used electrical erosion and mechanical abrasion resulting in high MRR. But in the case of the EDD process, electrical erosion with rotating tool electrode helps to increase MRR than EDM. As in EDM, only electrical erosion takes place so MRR found lowest.

ii) In EDD, higher the peak current, higher the MRR as it removes softens material easily but less than EDDD because both electrical erosion and mechanical abrasion take place simultaneously causing higher MRR.

iii) In EDM, only electrical erosion takes place but no abrasion and rotary action so causing the least amount of MRR found.

iv) Higher pulse-on time (Ton), both MRR and TWR are higher as longer duration of on-time melts both electrode materials more.

v) Higher the pulse-off time (Toff), lower the MRR and TWR because of lesser available time to be on (Ton).

SEM analysis was also confirmed that maximum MRR found in the case of EDDD. Based on the evidence available from the experiment conducted above, the author suggested that EDDD is the best among all the mentioned processes.

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