Investigation and optimization of process parameters engineering essay

Engineering

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ABSTRACT

This paper aims to investigate the experimental results of the machining characteristics and the effect of process parameters during ultrasonic machining of titanium alloy (Ti-6Al-4V) through cryogenic treated tool material and evaluation of performance characteristics such as material removal rate and tool wear rate. The optimal parametric set of combination has been obtained using Taguchi method and the results have been confirmed through performing verification experiments. The SEM analysis of the machined surface has also been studied. The results indicate that with the utilization of the proposed method, material removal rate is improved by 0. 503 times and tool wear rate is decreased by 1. 37 times. The optimal parametric combinations and parametric effect will provide the guidelines for the researchers and the manufacturing engineers engaged for machining titanium alloy (Ti-6Al-4V). Keywords: Ultrasonic machining (USM); Titanium alloy (Ti6Al4V); Cryogenic treatment; Taguchi method

1. INTRODUCTION

Ultrasonic Machining (USM) is an advance manufacturing technology used to machine electrically conductive as well as non-conductive materials such as diamond, glass, semiconductors, ceramics, quartz etc. Titanium and its alloys can be machined by electrical discharge machining, laser beam machining but these processes have its own limitations such as proper surface finish, dimensional inaccuracies, recast layer and thermal stresses [1-2-3]. The highest strength to density ratio, resistance to heat and high corrosion resistance make it highly useful in various applications such as automotive, aerospace, human implants and protective armour on personnel carriers, naval ships and tanks. However the main reason for the demand of titanium in industries has been increased [4]. The Ultrasonic machining is an advance machining method that is used effectively for machining of titanium alloy to manufacture complex parts which exhibits problems during machining by conventional methods. Process parameters plays important role in machining performance characteristics, so proper selection of USM produces better results. The optimum parametric combinations like abrasive grit size, slurry concentration, power rating, tool feed rate and slurry flow rate for maximum MRR and minimum SR was obtained by CCD second-order rotatable design on ultrasonic drilling of hexagonal shaped hone on high alumina ceramics. The process performance i. e. MRR and SR was evaluated by using ANOVA [5]. Guzzo and Shinohara analyzed the abrasion of brittle and hard materials such as quartz are usually machined by USM [6]. Cutting force, (Fc) and surface roughness (Ra) were analyzed during turning of titanium alloy. Proposed mathematical models were developed from two-level factorial experimentation to define the performance indicator within the limit of factors. Cutting speed, feed and depth of cut were the highly significant process parameters that impact on Ra and Fc [7]. Authors found that there was linear relationship between MRR and hardness of cutting tool.

During the USM, ample quantities of fluid used for cutting and efficient flow of slurry are necessary in order to remove the heat from the machining zone during machining of titanium alloy. Rigidity of tool joined in the horn ensures the proper maintenance for depth of cut. [8]. Singh and Khamba analyzed the USM of titanium alloy and pure titanium, to develop the mathematical model for USM responses [9]. During machining by USM, mechanical properties of workpiece play significant effect on performance characteristics such as MRR, TWR, and Ra. Singh and Khamba studied the USM of tough materials like titanium alloy [10]. From literature survey, it was found that significant machining was done by cooling the workpiece and tool at low temperature using a cryogenic treatment. Cryogenic treatment is an eco-friendly, non-toxic and non-explosive technology. The effects on various types of steel and other material to investigate the process to optimize the parameters using various approaches have been used for cryogenic treatment. Cryogenic treatments of material produces the significant increases in wear resistance, hardness, toughness and produce the significant decrease in residual stresses, chemical degradation because retained austenite transforms into martensite [11]. To understand the behavior of distortion of the electrode and to establish the applications of liquid nitrogen in reducing distortion of the electrode during EDM of M2 grade high speed steel using cryogenically cooled copper electrode and conventional electrode [12]. To attain less wear resistance of 4140 steel, the deep cryogenic treated process parameters are optimized using analysis of variance. The four process parameters, namely hardening temperature, soaked period, temperature and period of tempering , are considered for the optimization and concluded that the hardening temperature play a significant role having percentage influence of 17. 34% from other process parameters . [13]. Nirmal et. al analyzed that the retained austenite after treatment was near 0%. The laboratory test on lathe tool didn't indicate any effect on hardness of treated tool while on rapid facing test, it was discovered that cryogenically treated tool presented longer tool lives at different spindle speed and feed rates. Significant properties like fatigue behaviour on the tool life due to variation in stresses and deformation in tool were analyzed and concluded that cryogenic treatment constraint the fine carbide and displacement of martensite for maximum fatigue load results maximum tool life [14]. The cryogenic treatment to conventionally machined Ti-6Al-4V alloy was carried out to evaluate the cutting temperature to machine different alloys under different set of cooling conditions. Jet liquid nitrogen was used to provide the cooling at cutting interface and results of various cooling approaches were found [15]. The study concluded that, applying liquid nitrogen near to the cutting tool edge has a tendency to reduce the tool temperature of cutting zone. It was also found that titanium diffusion to tool material becomes negligible because of cryogenic cooling which otherwise was the major factor for the tool wear during the machining of titanium alloy. Literature survey on the Ultrasonic machining of titanium alloy (Ti-6Al-4V) reveals that no work on cryogenic treatment of tool material was used while machining Ti-6Al-4V alloy. In the present investigation L18 orthogonal array (35) has been selected to design the experiments. The optimal parametric set of combinations of process parameters for the machining of Ti-6Al-4V alloy has been analyzed by signal to noise ratio (S/N ratio). Machining characteristics of Ti-6Al-4V alloy has been explored using USM for their application in concerned manufacturing industry.

2. EXPERIMENTAL SETUP

Experimental trials have been performed in an Ultrasonic drilling machine (model: AP-500; make: Sonic Mill, USA) as shown in Figure 1. Experimental trials have been performed i. e. based on different process parameters like tool material, abrasives, grit size, slurry concentration and power rating. The tool dimensions have been decided, based on the horn shape to save the machining operation time. Titanium alloy (Ti-6Al-4V, composition: C= 0. 1%, Fe= 0. 30%, Al= 6. 05%, O= 0. 25%, N= 0. 03%, V= 4. 1%, H= 0. 015% and balance Ti) with yield strength of 828 GPa, density of 4. 42 g/cm3and hardness of 396 HV were selected as work material of 900 mm x 500 mm x 10mm plate. Cryogenic treated tool of high carbon steel (HCS), high speed steel (HSS) and stainless steel (SS) with straight cylindrical cross-section having diameter 10 mm has also been used in this investigation. Performance of ultrasonic machining of titanium alloy is evaluated on the basis of MRR and TWR. The optimal parametric set of combination of process parameters has been obtained using Taguchi method for maximization of MRR and minimization of TWR in USM. MRR and TWR has been calculated using equation 1 and 2 respectively…. eqn. 1… eqn. 2Where;= initial and final weight of workpiece (gms); = initial and final weight of tool; = Density of Ti-6Al-4V in gms/; = Density of different tools in gms/ ; t = machining time (min.); Table 1. Experimental Process parameters and their range values at various levelsFig. 1 Ultrasonic drilling machine Fig. 2 Scanning Electron MicroscopeL18 (35) standard orthogonal array, which has 18 rows according to the number of experimentation was selected for present investigation. The process parameters like tool material, abrasives, grit size, slurry concentration and power rating have three levels each, as shown in table 1. Figure 2, the Scanning Electron Microscope, (model: EVO® MA 15; make: ZEISS, Germany) was used to identify the microstructural changes during the USM process.

3. RESULTS AND DISCUSSIONS

The experimental results show the effect of process variables on process performance characteristics i. e. MRR and TWR. Table 2 shows the experimental control log as per L18 orthogonal array. Each trial has replicated three times; hence total 54 experiments were performed in entirely random manner in order to minimize the interference caused by irrelevant process parameters. In Taguchi’s design approach, the deviation between the predicted value and the experimental value of performance characteristics is denoted by a loss function which further transformed into signal to noise ratio (S/N ratio). In order to analyse the S/N ratio of the performance characteristics, three different approaches such as lower-the-better, higher-the-better and nominal-the-best are used. Table 2. Experimental control log as per L18 orthogonal arrayHere the main purpose for present investigation is the maximization of MRR and for minimization of TWR represents better machining performance; hence the " higher-the-better" type characteristics (equation 3) is selected for MRR and " lower-is-better" type characteristics (equation 4) is selected for TWR to obtain optimal machining performance.----- eqn. 3----- eqn. 4Where: yi is the experimental result values at the ith observation and n is the number of observations. Table 3 shows the average value of three trials that is used as response variables for performance characteristics and S/N ratio is calculated for every single trial. Figure 3 and 4 shows the parametric effects on MRR and TWR respectively. MINITAB (version 14. 0) software has been used to do the analysis of experiments so that best optimal set of parameters can be obtained. Table 3. Results for MRR and TWRFigure 3 shows that the maximum MRR was observed when stainless steel was used as a tool material perform better than other tool materials because of high hardness of stainless steel. If the hardness ratio of tool and workpiece is more, indentation in tool and workpiece increases. It can be observed that MRR increases with the increase of hardness of workpiece and tool material both Indentation due to abrasive grain in tool and workpiece is inversely proportional to the hardness ratio of tool and workpiece. Because of cryogenic treatment the force of the tool become harder, thereby created more impact on abrasive (rather than embedding into the tool force) to create larger penetration depth on workpiece. It can be observed that the MRR increases with the use of boron carbide as compared to aluminium alloy and silicon carbide as abrasive because of high hardness of grains which results faster destruction of work surface. Increase in coarseness of the abrasives grain size improves the MRR. The increase of grit size means the coarseness of the abrasive particles reduces. Hence lower grit size of 220 promotes more efficient machining of titanium based alloy and higher slurry concentration yield higher MRR. Power rating also plays a significant role for higher MRR. Increase in power rating substantially improves the rate of machining. Fig. 3 Parametric effect on MRR Fig. 4 Parametric effect on

TWRFigure 4 shows the parametric effect on TWR. It can be concluded that cryogenic treated SS tool recorded higher significant effect as compared to HCS and HSS tools because of higher hardness. The abrasive (Boron carbide) used for experimentation having 500 grit size makes significant effect on TWR. Due to much finer grains the harder of tool by cryogenic treatment does not affect tool surface, since major mode of MRR may be due to grains kinetic energy by nitration of tool. Thus penetration by abrasive all over the machined surface shows uniformity. The effect of power rating on TWR is similar as on MRR. Higher power rating lead to be higher TWR. With the use of cryogenic treatment of tool, dimensional error while machining has been reduced and improve machining accuracy.

3. 1 Prediction of Optimum Levels

Experimental analysis using ANOVA predicts the significant process parameters and to establish the optimal parametric set of combinations for USM of titanium alloy (Ti-6Al-4V). Pooled analysis of variance (ANOVA) for MRR as shown in table 4, reveals that boron carbide as an abrasive is recognized a higher significant process parameter with an F-value of 19. 92 and P-value of 0. 00 followed by tool material, power rating and grit size . In the present investigation, higher the better value for MRR is considered for analysis. Hence from figure 3, it can be observed that maximum MRR was achieved by using tool made up of stainless steel and abrasive is of boron carbide at 3rd level, grit size of 220 at 1st level and power rating of 400W at 3rd level, so the optimal parametric set of combination for maximum MRR is A3B3C1E3. For TWR, abrasive used for machining plays a most significant role in USM of titanium alloy with F value of 6. 76 and p value of 0. 003

followed by tool made up of stainless steel and power rating of 400W is also considered as significant parameters. Lower-the-better value for TWR is considered for analysis during investigation. From figure 4, it can be concluded that minimum TWR was achieved by using tool material made up of stainless steel, abrasive is of boron carbide and power rating of 400W at 3rd level, so the optimal parametric set of combination for minimum TWR is A3B3E3. Table 4. Pooled analysis of variance (ANOVA) results for MRR and TWR

3. 2 Estimation of Optimum Response Characteristics

In this section, the optimal values of the response characteristics e. g. MRR and TWR along with their respective confidence intervals have been predicted. Considering the influence of significant parameters, the optimal set of values of each response characteristic is predicted. The predictable mean of the MRR is determined utilizing the relation described by [16] and [17-18] as shown in equation 5;.....eqn. 5Where, MRR1, MRR2, and MRR3 values are taken from the Table 3. The predictable mean value for MRR is calculated as: µMRR = 0. 6121mm3/minThe average value of response characteristics from verification experiments must be within the 95% confidence interval called (CICE) and the average value of response characteristics from verification experiments may or may not be lies within the 95% confidence interval called mean of population (CIPOP) are obtained by using equations 6 and 7 as rewritten below for ready reference:........ eqn. 6.........eqn. 7Where, = confidence level of (1-α) against 1 degree of freedom with error degree of freedom; neff = 6; N = Total number of designed experiments = 54; R = Number of trial experiments = 3;= Error variance for

MRR = 0. 0073 and = error degree of freedom = 45 (Table 4);(1, 45) = 4. 06 (from tabularized ƒ value)So CICE = ± 0. 1220, and CIPOP = ± 0. 0704Therefore, the expected confidence interval for verification tests is: MeanµMRR-CICE <µMRR 4. CONFIRMATION EXPERIMENT In order to confirm the predicted response results, three verification experiments have been performed for each of the response characteristics i. e. MRR and TWR at optimal levels of process variables. The confirmation experiment results obtained using optimal machining parameters for performance characteristics such as MRR and TWR as shown in Table 5. Table 5. Confirmation experiment results for MRR and TWRThe actual improvements of the average value of MRR and TWR for each optimal set of machining parameters with respect to preliminary set of machining parameters. Improvement of average MRR is obtained after conducting three experiments trial runs on preliminary to the optimal machining parameters is 0. 328mm3/min. and improvement of average TWR is 0. 061mm3/min in ultrasonic machining of Ti-6Al-4V alloy.

5. MICROSTRUCTURE ANALYSIS

The microstructure has been studied by the scanning electron micrograph (SEM) at a magnification of 250X. Figure 5 depicts the microstructure of the machined surface at optimal parametric combination (A3B3C1E3). It is observed that the cryogenic treatment does not show the mesh improvement in MRR due to increase in power rating but undulations on machined surface earned to be minimized after cryogenic treatment. Boron carbide having 500 grit sizes of fine particles does not affect tool surface due to harder of tool by cryogenic treatment, since major mode of MRR may be due to grains kinetic energy by nitration of the tool. Thus penetration by abrasives all over the machined surface shows uniformity. Figure 5. SEM micrograph of the machined surface at optimal parametric combination.

6. CONCLUSION

This research work is an effort to find the optimal parametric combination of ultrasonic machining process for MRR and TWR on Ti-6Al-4V alloy. Higher value of MRR i. e. 0. 697mm3/min and lower value of TWR i. e. 0. 166 mm3/min indicates that the Ti-6Al-4V alloy can be machined effectively by USM. The optimal parametric set of combinations for higher MRR is A3B3C1E3 and for minimum TWR is A3B3E3 which indicates the improvement 0. 503 times in MRR and 1. 37 times in TWR respectively. The predicted optimal range for material removal rate at 95% confidence level is CICE: 0. 4901 < μMRR < 0. 7341; CIPOP: 0. 5417 < μMRR < 0. 6825 and for tool wear rate is CICE: 0. 1421 < μTWR < 0. 2055; CIPOP: 0. 1570 < μMRR < 0. 1758.