Simulation Modelling Practice and Theory 62 (2016) 31–48

Contents lists available at ScienceDirect

Simulation Modelling Practice and Theory

journal homepage: www.elsevier.com/locate/simpat

Simulation and optimization of machining parameters in drilling of titanium alloys

Suman Chatterjee, Siba Sankar Mahapatra*, Kumar Abhishek

National Institute of Technology, Rourkela 769 008, India

ARTICLE INFO

Article history:
Received 5 February 2015
Revised 7 December 2015
Accepted 14 December 2015

Keywords:
Drilling
Thrust
Torque
Circularity
Harmony search (HS)
Finite element method
Titanium alloy

ABSTRACT

The present study attempts to analyse the effect of various drilling parameters such as spindle speed, feed rate and drill bit diameter on performance characteristics such as thrust force, torque and circularity at entry and exit of the holes in drilling of titanium alloy using coated drill bit. A three dimensional machining model based on Lagrangian approach is developed using DEFORM-3D software. The performance characteristics obtained through simulation model is compared with experimental results. The simulation model closely agree with the experimental results as percentage relative error of 4.93, 9.01, 6.04 and 3.0 is observed for thrust, torque circularity at entry and circularity at exit respectively. The experimental data is used to develop valid empirical models to relate performance characteristics with drilling parameters using non-linear regression analysis. The empirical model helps to predict various performance characteristics without resorting to rigorous analysis through the numerical model. The values of various performance characteristics predicted from empirical models are compared with experimental results and the percentage relative error within 10% is observed. Finally, an improved version of latest evolutionary approach known as Harmony Search (HS) algorithm has been proposed to obtain favorable machining conditions through optimization of each performance characteristic. The optimal value of circularity at entry is obtained as 0.985 (approaching towards ideal value of one) when spindle speed, feed rate and drill bit diameter are set at 530.86 (≈531) RPM, 44.8 (≈45) mm/min and 7 mm, respectively. Similarly, optimal value of circularity at exit reaches 0.979 with same spindle speed and drill bit diameter but feed rate of 50 mm/min.

1. Introduction

Titanium alloys are extensively used in manufacturing industries due to their excellent properties such as high strength to weight ratio and corrosion resistance even at elevated temperature [1]. Among many titanium alloys, Ti6Al4V is extensively used in aerospace applications due to its favorable mechanical properties. Not only in aerospace applications but also Ti6Al4V is used in bio-medical engineering, turbine blade manufacturing, bone supplement in bone grafting, automobile and chemical industries [1–3]. Arrazola et al. [4,5] have reported through extensive experimental studies at various machining conditions that titanium alloys have poor machinability. Due to high heat generation during machining (because of low thermal conductivity), it is difficult to drill the Ti6Al4V alloy as it leads to rapid tool wear occurring at the tip of tool and

* Corresponding author. Tel.: +916612462512.
E-mail addresses: mrsumanmech@gmail.com (S. Chatterjee), mahapatrass2003@gmail.com (S.S. Mahapatra), krabhishek1987@gmail.com (K. Abhishek).

http://dx.doi.org/10.1016/j.simpat.2015.12.004

workpiece interface [6]. As it is chemically reactive with most of the tool materials, a strong adhesion wear occurs resulting in tool failure. Therefore, it is vital to investigate the machinability of Ti6Al4V because such a material causes excessive tool wear and generation of high temperature during conventional machining. The drilling operation is one of the important machining processes used for making holes needed specially for the assembling of parts.

During drilling, the forces acting on the cutting edge against the work piece leads to cutting off chips from the hole as it is drilled. Cantero et al. [7] have performed dry drilling on Ti6Al4V with TiN-coated carbide drill bit at different machining conditions for continuous drilling of work piece. The study emphasizes on finding out appropriate machining condition that leads to reduce the tool wear and hence increase tool life. Hong and Ding [8] have conducted machining operation under cryogenic environment using liquid nitrogen as a coolant to reduce tool temperature in machining of Ti6Al4V. The study reveals that the cryogenic cooling during drilling operation leads to increase the cutting speed but tool life can be maintained if the cutting speed is restricted to 1 m/s.

Marasi [9] has developed a two dimensional model in DEFORM-2D to study the effect of cutting speed and feed rate during turning of Ti6Al4V. The experimental runs are designed as per design of experiment (DOE) approach. The study indicates that that cutting force increases with cutting speed. Poutord et al. [10] have examined the effect of drilling parameters on thrust force and torque in drilling of Ti6Al4V and carbon fiber reinforced polymers (CFRP) using tungsten carbide (WC) drill bit (Grade K20). Singh et al. [11] have proposed emperical models to predict the thrust and torque during drilling of unidirectional glass fibre reinforced plastic (UD-GFRP) composites. The authors have also proposed finite element (FE) model to analyze the delamination and failures of glass fibres near the drilled holes.

Kadirgama et al. [12] has implemented response surface methodology (RSM) approach coupled with finite element analysis (FEA) to analyse influence of cutting parameters on material removal rate in milling operation. Bagci and Ozcelik [13] have proposed a finite element model for the dry drilling of AISI 1040 steel and Al 7075-T651 using TiAlN/TiN coated drill bit to predict the temperature at tool tip and work piece interface. Kyratsis et al. [14] has implemented the Taguchi approach along with FEA to predict the thrust force in drilling operation. They have suggested a empirical models relating process parameters and performance characteristics.

Past studies suggest that good number of attempts have been made to develop finite element models to predict the outputs such as temperature distribution at tool tip and work piece interface, quality of drilled hole, thrust force and cutting force individually. However, a simple valid model for predicting more than one performance characteristics in drilling operation using finite element approach is not adequately addressed in the literature. Therefore, the present study proposes a finite element model for predicting performance characteristics such as hole quality in terms of circularity at entry and exit, thrust force and torque. Further, adoption of statistical design of experiments (DOE) approach for designing experimental strategy of simulation model can substantially reduce not only simulation runs but also computational time to obtain related information. Simulation of drilling of Ti6Al4V work piece by finite element analysis can explore various process related issues as difficulties arise in the machining of Ti6Al4V. Specifically, this paper aims at highlighting the influence of drilling parameters on performance characteristics such as circularity of holes, thrust force and torque in drilling of Ti6Al4V by conducting experiments based on response surface methodology (RSM) approach. Valid quadratic process models have been proposed relating performance characteristics with drilling parameters to ease the tool engineers to predict the performance characteristics. Simulation of drilling has been performed in finite element method based software DEFORM-3D 6.1 V. The experimental results are compared with simulation model. It is observed that the simulation results are in good agreement with the experimental values. Finally, the process models are used to obtain the optimal values of process parameters using recently proposed meta-heuristic known as harmony search (HS) algorithm. The rationale for using HS algorithm lies in the fact that it needs less memory requirement and possesses the capability of finding optimal solutions for continuous optimization problems with less computational time with few adjustment parameters [15,16].

2. Experimental details

Response surface methodology (RSM) is basically a collection of statistical and mathematical technique useful for influence of several input variables on performance measures of a process. It is a sequential process that leads to optimization of process variables for best performance measures. The methodology is quite efficient as compared other design of experiment approaches in planning experimental strategy because experimental points are not to factorial points or fraction of factorial points. Rather, it uses the factorial points, axial points and centre points to plan the experimental strategy [17]. Kyratsis et al. [14] have used response surface methodology to design the experimental and simulation strategies to study the parametric effect of drilling operation on thrust force. Rajamurugan et al. [18] has used response surface methodology to plan experiments for developing a relationship between machining parameters (rotational speed, feed rate, drill bit diameter and fiber orientation angle) and performance measures in drilling of glass fibre reinforces plastic composites. The response surface methodology comprises a regression surface fitting to develop an appropriate approximation model between the response 'Y' and independent variables $\{X_1, X_2, \ldots X_N\}$. In general, the relationship is written in the form of:

$$Y = f(X_1, X_2 \ldots X_n) + \varepsilon \tag{1}$$

where the form of the true response function Y is unknown and ε is a term that represents other sources of variability not accomplished for in Y. It usually includes the effect of measurement error in response, background noise, other variables