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MODELING OF ADVANCED MACHINING PROCESSES: A REVIEW

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Abstract:

This study provides a review on past work conducted on non-conventional machining of tool and die steels and advanced materials. Experimental investigations on surface grinding of advanced materials have also been discussed. The last section of the manuscript provides a review of available literature on advance machining process and its behavior during machining of the different kind of materials. Material removal and its mechanism for machining processes have been one of the primary concerns of researchers for several years. It becomes easier to predict the effect of various input parameters of the process after complete understanding of its material removal mechanism. Several past researchers have explained the material removal mechanism of hybrid machining processes by developing thermal models to predict the effect of energy interactions in different machining processes. This study is an attempt to discuss the same.

Literature review:

The modeling of the machining process can be described as a mathematical formulation that establishes the relation between input and output parameters in order to predict the performance of the machining process. The purpose of modeling a machining operation is to develop a predictive capability for machining performance well in advance and finally to achieve optimum productivity, quality and cost (Van Luttervelt et al., 1998). The mathematical modeling of machining processes is required for the simulation of the process, design and optimization of the process and control of the process (Tönshoff et al., 1992). This section describes the modeling and optimization of advanced machining processes.

Abrasive Water Jet Machining Process (AWJM) utilizes energy of high velocity water jet mixed with abrasives to machine brittle materials. In this processhigh momentum of water jet is transferred to the abrasives particles for the erosion of material from the workpiece surface. AWJM machining process can effectively machine materials like copper, aluminum, lead, tungsten carbide, titanium, ceramics, silica glass and composites. Hashish used erosion model of Finnie (Finnie, 1960) to develop a model to determine combined depth of cut due to deformation and cutting wear. The use of the model was restricted to brittle materials only and the effect of abrasive particle size and shape has not been considered in the investigation (Hashish, 1989).

An investigation on mechanism of material removal for laser and abrasive water jet cutting was carried out by Singh J et al. The mechanics of these two processes was studied to elucidate the mechanism of material removal for Ti-6Al-4V and A286 steel. In this study the effect of various control parameters on fatigue behavior of titanium and steel was investigated (Singh and Jain, 1995).

Arola and Ramulu (1997) discussed experimental study on the effect of material properties on surface integrity and texture of machinedmaterials during AJM. Models of dry abrasive erosion were used to analyze the influence of material properties on the hydrodynamic erosion process. The study reveals that the depth of sub surface plastic deformation is inversely proportional to strength coefficient and observed to be higher at the entry of jet.

Sang Choi and Heung Choi (1997) developed an analytical model for the evaluation of material removal by the single abrasive particle and thickness of fracture on the work material.

Hassan and Kosmol (2001) conducted finite element modeling of AWJM to observe the effect of abrasive particle onworkpiece interaction. This model was used to predict the depth of deformation caused by the impact of abrasive particles. The primary objective of the study was to develop finite element model of AWJM for the prediction of the depth of cut without experimentation. This model was based upon performance of workpiece material under dynamic loading of AWJ conditions. This model determined the forces acting on abrasive particles. It was concluded that plastic deformation was highly localized during machining of materials.

Liu et al. (2004)developed computational fluid dynamics (CFD) models for ultra high velocity water jet using Fluent 6 flow solver. During the study the dynamic characteristics of downstream jet from very fine nozzle under steady state and turbulent flow conditions were investigated. Water and particle velocities in a jet were obtained under different input and boundary conditions to determine jet characteristics and kerf formation. It was observed from the study that there is an initial rapid decay of axial velocity at jet center, however cross-sectional flow moves toward the top hat profile at downstream.

Wang and Wang (2010) conducted theoretical analysis to develop a flow for AWJ. The objective of the study is to predict behavior of abrasive particles during AJM. The study proposed a two fluid model. A control volume method was used to solve the equations and a phase coupled algorithm was used to solve the pressure velocity equations. A 2D quasi flow field outside the conventional nozzle was used in AWJ analysis to validate the model.

Mostofa et al. (2010)presented CFD and theoretical analysis to optimize the mixing of components by multiphase approach. Water, air and abrasives were mixed in mixing the chamber. The developed model was used to predict the effect of air and abrasives mixture on the process performance. The experimental results concluded that the nozzle length has a considerable effect on the mixing of water, air and abrasives. The velocity of water jet affected the erosion rate mostly at the wall of the nozzle. It was also reported that erosion in the nozzle body is higher at initial zone and volume fraction of air increases with the increase in length of thenozzle.

Ultrasonic machining (USM) is one of the nontraditional modern machining processes. In this process, material is removed by the dynamic action of abrasive grains. The term ultrasonic is used to express the vibratory wave having a frequency above the upper limit of the human ear. The flow of abrasives is maintained by the abrasive slurry which drives the abrasives into the machining zone. The oscillatory tool moves perpendicular to the work surface with high frequency. Each and every abrasive moves with high momentum and strike the work surface to remove the material. This process is having the advantage of machining hard and brittle materials with better accuracy and high quality of surface finish.

Miller (1957) developed analytical models of MRR for USM to predict the performance of the process.The developed MRR model was based on plastic deformation of ductile materials. Later Kainth et al. (1979) reported a mathematical model to predict machining rate using properties of tool and workpiecematerials.

Lee and Chan (1997) developed an analytical model to predict the effect of amplitude of tool tip, static load and grit size of abrasives on MRR and surface roughness. The experimental results confirmed that an increase in amplitude of tool vibration, static load and grit sizes of abrasives increases MRR and SR.

Wang and Rajurkar (1996)suggested a realistic model based on stochastic and dynamic nature of the USM process. This model was purely meant for brittle materials only.

Komaraiah et al. (1988) conducted experimental investigation into USM for glass, porcelain, ferrite and alumina using various types of tool materials. This study reveals the effect of mechanical properties of the workpiece and tool materials on surface roughness and accuracy.The effect of size, type of abrasives, amplitude of tool oscillations and workpiece rotation was also investigated on MRR.

Rotary USM is a hybrid machining process which removes material due to the combined effect of USM and grinding process. This process has the potential of higher MRR and accuracy with minimum surface damage. The rotary mode of USM has found positive effects on machining characteristics as compared to conventional USM.

Hu et al. (2002) proposed an analytical model for MRR during rotary ultrasonic machining of ceramics. This study was conducted with experimental design of five factors at two levels to develop a correlation between machining parameters and MRR. The theory of mechanics investigated the crack propagation on the workpiece during machining.

Huang and Liao (2003)used grey relational and S/N ratio analysis to examine the influence of table feed and pulse on time on MRR.Tosun et al., (2003)experimentally investigated the effect of pulse duration, open circuit voltage, wire speed and dielectric fluid pressure on SR. It was observed that an increase in pulse duration, open circuit voltage and wire speed causes an increase in surface roughness; however increase in dielectric fluid pressure cause a decrease in surface roughness.

Saha et al., (2004) developed a finite element model to predict the temperature distribution onworkpiece during WEDM. This model was used to optimize the different parameters to prevent wire breakage during the process. The transient analysis mapped the heat distribution profile of the wire at any point on the wire. This model was used to predict the temperature distribution profiles of the wires made up of different materials. This same model was used to develop the smart electro discharge machining system with a sensor to increase the cutting speed with minimize wire breakage.

Kanlayasiri and Boonmung (2007) developed a mathematical model using regression method to evaluate the pulse on-time and peak current for minimum surface roughness.

Hargrove and Ding (2007)developed an FEA program to model temperature distribution of the workpiece under different machining conditions. The thickness of temperature affected layers for different input parameters was computed on the basis of critical temperature value. This study wasfound to be supportive in developing advanced control strategies to enhance complex machining capabilities and machining rates with minimum surface damage.

Kumar and Khamba (2009) proposed a mathematical model to analyze MRR during rotary USM. Taguchi multi-objective optimization technique was applied to predict the optimum combination of machining parameters like type of abrasive slurry, size and concentration of abrasives, tool material and rating of the machine during machining of satellite. Singh and Gill (2009)carried out fuzzy modeling and simulation of ultrasonic drilling of porcelain ceramic with hollow stainless steel tools.

WEDM is a thermoelectric process in which heat energy of the spark is used to remove material from the workpiece(Jain, 2009). The workpiece and tool electrode are electrically conductive in WEDM. It utilizes a continuously travelling wire electrode made up of copper, brass or tungsten. On therelease of appropriatevoltage, dischargesoccur between the wire and the workpiece in the presence of dielectric fluid. WEDM has been widely acceptedas advanced machining process used to producethe intricate shapes and profiles. It is used in industries for modern tooling applications. High strength to weight materials such as advanced ceramics and composite materials can be easily machined by this process.

Powder mixed electrical discharge machining (PMEDM) of EN-8 steel was conducted by Ojha et al. to optimize material removal rate and tool wear rate (Ojha et al., 2011). The effect of current, duty cycle, angle of electrode and concentration of chromium powder in thedielectric fluid were investigated on performance of PMEDM. The study concluded that theconcentration of powder has asignificant effect on MRR whereas, current, electrode angle are found to be dominant parameters for TWR.

The experimental trials on micro-EDM was carried out under different levels of applied energy, voltage, maximum current and pulse duration in order to identify the effects of these process conditions on the obtainable surface roughness, wear ratio, craters and spark gap. The grain size of the material has observed to be thedominant effect on the quality of the machined part. The results of the investigation have revealed that, by refining the material microstructure, a better surface finish can be achieved(Elkaseer et al., 2013).

Singh and Pandey (2014) conducted rotary disk electrical dischargemachining of Nimonics 75 super alloy to observe the effect of peak current,peak voltage, pulse on-time, pulse off-time, speed and aspect ratio of diskelectrode on material removal rate, disk electrode wear rate and surfaceroughness. The study concluded that the aspect ratio of disk electrode andpeak current significantly affect the process machining characteristics. Therotation of disk causes efficient removal of debris and stabilised machiningwhich results in minimum recast layer.

Several attempts have been madein the pastto study the influence of different process parameters on the performance measures such as cutting rate, surface finish and MRR with differentmathematical modeling techniques.

Few authors have reported the mathematical modeling of EDSG process. Kozak purposed a predictive model using Artificial Neural Network (ANN) of AEDG process for determination of machining characteristics (Kozak, 2002). The neural and genetic training strategies were applied for the prediction of machining characteristics in AEDG process.

Conclusions:

1. Among the discussed literature, it is evident that a lot of work has been done on machining of Tool steel and advanced materials by conventional and non-conventional machining processes. The outcome of the past research is to improve the material removal rate and surface finish of the machined component.
2. There is also a need to explore the effect of hybrid energies during machining of hard and conductive materials. From the review of literature it is cleared that the quantum of energy released during the machining process can be controlled by the process parameters to improve material removal and surface finish of the workpiece.
3. Apart from this published literature, limited information is available on the machining of composite materials by the composite tool electrodes. The outcome of the study will enhance the opportunities of composites toward manufacturing technology.

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