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A Review on Application of Soft Computing Techniques & Analytical Techniques in Machining Performance Prediction and Optimization under MQL

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ABSTRACT: *Minimal Quantity Lubrication (MQL) plays a significant role in machining operations due to environmental benefits and reduced production costs. A number of researchers have recently shown great interest in this topic especially in the area of understanding the effects of various synthetic and vegetable oils as cutting fluid in MQL systems. Several papers have been published on this topic using different machining operations such as turning, milling, drilling, grinding etc. This paper presents the state-of-the-art in predictive performance models and optimization of machining using MQL. Major soft computing tools applied for this purpose are fuzzy logic, genetic algorithms, Taguchi design and response surface methodology, D-optimal method, principal component analysis and grey relational analysis. The physical process is described and the main process parameters that are relevant to its modeling & optimization are highlighted.*

Keywords: *Machining, Minimal Quantity Lubrication, empirical modelling, analytical modelling.*

I. INTRODUCTION

A minimal quantity lubrication system (MQL) has the task of delivering minute quantities of lubricant to the active site between the tool and workpiece when cutting or non-cutting operations are involved. Lubrication is performed by an aerosol that is formed by oil droplets that are finely dispersed in an air stream [1]. The main feature of MQL is the feeding of the exact metered quantity of oil directly to the tool operating area. Heat is dissipated primarily via the swarf.

Other important features of the MQL based machining process are:

1) It requires the handling of both the cutting fluid and highly compressed air, thus the task of cooling and lubrication is shared between the compressed air and the cutting fluid. On one hand, the cutting fluid provides the lubricating effect while the highly pressurized air fulfils the job of cooling the machining zone.
2) This process only requires a very low power output for transporting the MQL oil.
3) The MQL vaporizes completely and immediately at the tool cutting edge.
4) The machining system and the workpieces remain virtually oil-free.
5) The swarf is dry and can be recycled directly.

Typically of a flow rate of 50 to 500 ml/hour, in an air flow directed towards the cutting zone [2]. The amount of coolant used in MQL is about 3-4 order magnitude lower than the amount commonly used in flood cooling condition. For example, in flood cooling up to 10 liters of fluid can be dispensed per minute. The lubricant is sprayed by means of an external supply system which can be one or more nozzles. In regular machining operations that use a flood coolant supply, cutting fluids have been selected mainly on the basis of their characteristics, i.e., their cutting performance. In MQL however, secondary characteristics of a lubricant are important, such as their safety properties, (environment pollution and human contact), bio-degradability, oxidation and storage stability. This is important because the lubricant must be compatible with the environment and resistant to long term usage caused by low consumption [3]. In MQL, lubrication is obtained via the lubricant, while a minimum cooling action is achieved by the pressurized air that reaches the cutting surface.

Minimal quantity lubrication (MQL) can be fed to the tool or workpiece in two different ways, internal or external [4]:

Internal MQL: with the internal lubrication method, compressed air or the aerosol is applied through the spindle, the tool holder and the tool directly at the point between tool and workpiece. The oil performs the lubricating function while highly pressurized compressed air performs the cooling action. **External MQL**: with the external lubrication method, the mixing of oil and compressed air is done in a separate mixing chamber and the aerosol is supplied to the lubrication point from the outside through nozzles.

Even though there have been many review articles on this topic but this endeavor has its own intrinsic worth. A careful effort has been made to report the soft computing approaches used for modeling and optimization of machining processes under MQL system. Additionally, it also helps in the research being carried out by contemporaries in this area. The various modeling techniques in machining processes can be categorized as Mechanistic modeling and Empirical modeling [5]. The functional relationship between the input-output and in process parameters determined analytically for a cutting process is called mechanistic model. On the other hand Empirical models establish the relationship between the input parameters (decision variables) and the output parameters (responses). The present review paper is broadly divided into following sections: Introduction is presented first followed by review of research papers on empirical modeling & optimization using soft computing techniques and review of research papers on analytical modeling and conclusions from the present review is listed lastly.

II. RESEARCH PAPERS ON EMPIRICAL MODELING & OPTIMIZATION USING SOFT COMPUTING TECHNIQUES

Asif Iqbal et.al.[6] has modeled the effects of cutting parameters in MQL-employed finish hard-milling process using D-optimal method. In his research work, the effects of four parameters, namely, hardened steel's microstructure, workpiece inclination angle, cutting speed, and radial depth of cut were studied upon tool life and surface roughness. For tool life, workpiece material was found as the most influential parameter followed by the rotational speed of tool. High values of tool's rotational speed proved unfavorable for tool life but favorable for surface finish. Arup Kumar Nandi et.al.[7] have investigated on fuzzy rule based model based on Mamdani and TSK-types of fuzzy logic rules with different shapes of MFDs for prediction and performance analysis of machining with MQL in drilling of aluminum alloy.

Murat Sarıkaya et.al.[8] have evaluated Surface quality for different combination of cutting conditions. The results are analyzed using surface graphs and *S*/*N* ratios. Taguchi design, RSM and desirability function are conducted for optimization. Mathematical models were developed to formulate the input machining parameters for Ra and Rz. Application of MQL is a good tool in order to decrease of the surface roughness.

ZhiQiang Liu et.al.[9] have presented a new flexible method referring to coupling response surface methodology (CRSM) to acquire optimum cutting parameters in machining of difficult-to-cut titanium alloy under minimum quantity lubrication (MQL) condition, Murat Sarıkaya et.al.[10] performed multi response optimization of MQL based turning operation of cobalt base super alloy Haynes 25 which is a difficult-to-cut material. The cutting oil used is vegetable based oil. The process parameters which are cutting fluid, fluid flow rate and cutting speed were simultaneously optimized by taking the multi-response outputs by Taguchi based grey relational analysis into consideration.

Sundara Murthy and Rajendran et.al.[11] have used GA based ANN prediction model proposes to envisage the quality characteristics of surface roughness and tool wear in end milling experiments conducted beneath minimum quantity lubrication. The paper also deals with the multiple objective optimization with principal component analysis, grey relational analysis and Taguchi method. El-Hossainy et.al.[12] have performed experimental investigation to study the characteristics of the flow of the MWF in a turning process utilizing the MQL technique and to analyze the effect of the WMF's behavior on cutting force, surface roughness and tool wear. The Response Surface Methodology is used to develop mathematical models that relate the main cutting parameters, the workpiece material properties and the cutting fluid viscosity and flow rate with cutting force, surface roughness and tool wear. Multi-objective optimization problem was formulated with the objectives of minimizing production time and maximizing tool life which was solved using NSGA II.

Globočki Lakić et.al.[13] have presented the effect of using of minimal quantity lubrication (MQL) technique in turning operations on carbon steel C45E. Technological parameters: depth of cut, feed rate and cutting speed were adjusted to semi - machining and roughing Modelling was performed using regression analysis and artificial neural networks. KASIM et.al.[14] have used full factorial experimental design of the tool life of the end milled Inconel 718 under MQL . The experiments were performed using TiAlN-coated carbide. Mamun & Dhar et.al.[15] have presented the investigation is to evaluate the influence of MQL on chip formation mode and surface roughness in grinding AISI 1045 steel with CBN wheel at different level of process parameters using RSM.

Revankar et.al.[16] investigated the influence of cutting speed, feed rate and different amount of MQL on machining performance during turning of titanium alloy (Ti–6Al–4V) using poly crystalline diamond (PCD).

The experiments have been planned as per Taguchi's orthogonal array and the second order surface roughness model in terms of machining parameters was developed using response surface methodology (RSM).
Hussain et.al.[17] have investigated the MQL deep hole drilling method in automotive cast aluminum alloy using experimental design. Kuram and Ozcelik et.al.[18] have used fuzzy logic and regression for prediction of thrust force and surface roughness MQL drilling with vegetable based cutting oils. The work material used was AISI 304 with HSS-E cutting tool. The experiments were conducted using two types of vegetable oils**.**

III. RESEARCH PAPERS ON ANALYTICAL MODELING

Nilanjan Banerjee and Abhay Sharma et.al.[19] have presented a friction model as a function of the cutting speed and tool feed rate when machining with minimum quantity lubrication. The developed mechanistic model is utilized to understand the effects of machining conditions, temperature, and contact length of the tool-chip interface. Xia Ji and Steven Y Liang et.al.[20] have developed a residual stress prediction model as a function of cutting parameters, tool geometry, material properties, and lubrication conditions. The parametric study is carried out to investigate the effects of minimum quantity lubrication parameters, cutting parameters, and tool geometry on the cutting performances. Yamin Shao and Steven Y. Liang et.al.[21] have presented the predictive modeling of MQL grinding force through considerations of boundary lubrication condition, single grit interaction, wheel topography, material properties, and dynamic effects. The predicted tangential and normal forces were presented and compared to surface grinding experiment data.

Yamin Shao et.al.[22] have presented a physics-based model to predict residual stresses in grinding with consideration of the lubrication and cooling effects of MQL. They have developed an analytical relationship between residual stresses and process conditions such as process parameters, material properties, and lubrication conditions. Xia Ji et.al.[23] have developed a analytical model that predicts the residual stresses in machining under minimum quantity lubrication (MQL) condition as functions of cutting parameters, tool geometry, material properties as well as MQL application parameters. The residual stress prediction model is verified for orthogonal tube facing of TC4 alloy.
Pinaki Chakrabortya et.al.[24] have proposed a mixed effects model for the analysis of the longitudinal data obtained from a designed experiment on end-milling of AISI 4340 steel with multi-layer physical vapor deposition (PVD) coated carbide inserts under semi-dry and dry cutting conditions. Patrick Bolliga et.al.[25] have presented a method for modelling machining processes considering Minimum Quantity Lubrication (MQL) in a 2D and 3D FEM simulation by using the example of machining tempered steel AISI 4140 and also have experimentally validated these models.

IV. CONCLUSIONS

In this paper, a review of application of soft computing Techniques and analytical techniques in machining performance prediction and optimization has been presented. Lot of research work was conducted on MQL based machining systems hence it has been decided to present the review at one place so as to provide a complete picture to reader.
Following are the major observations from the literature:

1) Most of the popular soft computing techniques such as Regression analysis, Taguchi method, Principal component analysis, response surface analysis, grey relational method, fuzzy logic, neural network and genetic algorithms were used for modelling and optimization.
2) For empirical modeling and optimization, the input machining parameters considered were cutting speed, feed, depth of cut, tool geometry, type of cutting fluid, flow rate of cutting fluid, and cutting fluid viscosity while the response parameters considered for optimization were thrust force, surface roughness, tool wear, and tool life.
3) The analytical models developed have relied on finite element methods and computational fluid dynamics.
4) Considering its economy and environment friendliness, MQL is the best alternative for the conventional lubrication processes in the future machining operations.

V. RECOMMENDATIONS FOR FUTURE RESEARCH WORK

Empirical modeling and optimization of MQL arrangement for different combinations of oils, oil flow rates and air pressures should be examined and tool life estimation models under MQL may be developed. Modelling may be performed with evolutionary tools such as genetic programming and artificial bee colony program. Advanced CFD multiphase modeling techniques can be employed for analytical modeling.

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