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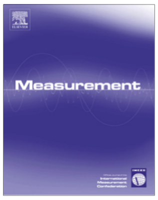

Influence of cutting fluid conditions and cutting parameters on surface roughness and tool wear in turning process using Taguchi method

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ABSTRACT

In this experimental work, the effect of various cutting fluid levels and cutting parameters on surface roughness and tool wear was studied. Taguchi orthogonal array was employed to minimize the number of experiments. The experiments were carried out on mild steel bar using a $TiCN + Al_2O_3 + TiN$ coated carbide tool insert in the CNC turning process. The effect of feed rate was found to be the dominant factor contributing 34.3% to surface roughness of the work-piece. The flow rate of the cutting fluid also showed a significant contribution (33.1%). However, cutting speed and depth of cut showed little contribution to surface roughness. On the other hand, cutting speed (43.1%) and depth of cut (35.8%) were the dominant factors influencing tool wear. However, application of cutting fluid (13.7%) showed a considerable contribution, while the feed rate gave the least contribution to tool wear. The optimum cutting conditions for desired surface roughness and tool wear were at a high level of cutting speed, medium level of depth of cut, low level of feed rate and low-flow high-velocity (LFHV) cutting fluid flow from the selected levels.

1. Introduction

Lubricants are widely used in all sectors of industry for cooling and lubricating the tool and work-piece interface in order to enhance machinability. Owing to the advantages of cutting fluids, their consumption in the machining industry is increasing rapidly. In 2005, the amount of lubricants used in machining was reported as nearly 38 Mt with an estimated increase of 1.2% over the next decade. Approximately 85% of the cutting fluids used around the world are mineral-based. The increased use of mineral and petroleum based oil causes several negative impacts on the environment and poses significant health hazards. It is reported that around 80% of all occupational infections of operators were due to skin contact with cutting fluids [26]. This is because the complex composition of cutting fluids can lead to irritant or allergenic properties. Because of hazardous substances, toxic and less biodegradable cutting fluids caused many techno-environmental problems and serious health problems, such as: lung cancer, respiratory diseases, dermatological and genetic diseases [20]. The International Agency for Research on Cancer (IARC) reported that petroleum-based cutting fluids, which contain heterocyclic and polyaromatic rings are carcinogenic and exposure to them could result in occupational skin cancer [1]. Therefore, in recent years, all costs involved with cutting fluids related to purchasing, recycling, and chip drying are increasing due to legislation from national and international authorities for environmental protection. For that reason, industries are emphasizing cleaner production processes in the machining process and product life cycle [8]. Minimum quantity lubrication (MQL), with

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environmental friendly cutting fluids, has been successfully applied in some of the machining processes.

Recently, biodegradable lubricants have been gradually replacing synthetic lubricants. Biodegradable cutting fluids that accomplish the lowest amount of environmental contamination can provide high reliability and satisfactory economic conditions. Additionally, the output of bio-based cutting fluids is cleaner and contributes less mist in the air, subsequently minimizing the occupational health risks [12]. Although bio-based (vegetation) cutting fluids are not perfect in all aspects, they have the least negative impact on the environment compared to other cutting fluids [5].

Various analytical methods for predicting surface roughness, tool life and cutting forces have been investigated by researchers. Development of empirical models for machinability parameters in a variety of machining process have been performed based on data mining techniques such as statistical design of experiments (Taguchi method, response surface methodology, etc.), computational neural networks, and genetic algorithms. All these methods provide the impact of each individual factor as well as the interactions between factors on the functional objective. Taguchi method is a systematic approach to find optimum values of design factors that lead to an economical design with low variability. Nalbant et al. [18] studied Taguchi parameter design for the purpose of demonstrating a systematic procedure in process control and recognized the optimum surface roughness performance with a more efficient combination of cutting parameters in turning process.

Dry machining is applicable for conventional machining on steels, steel alloys and cast irons except for aluminum alloys. Nonetheless, high friction between the tool and workpiece in dry cutting condition significantly increases the temperature resulting in higher level of abrasion, diffusion and oxidation. The workpiece also experiences a large amount of heat and consequently hinders the achievement of close tolerances and metallurgical damage occurs to its superficial layer [7]. Diniz and Micaroni [7] carried out turning experiments with variable cutting speed, feed and tool nose radius, with and without the use of cutting fluid to identify the best condition for dry cutting. They concluded that the use of cutting fluids in wet cooling can improve the tool life. However, dry cutting showed less power consumption and better surface finish.

Devillez et al. [6] investigated the effect of dry machining on surface integrity and cutting forces in turning of Inconel 718. Wet and dry turning tests were performed at various cutting speeds (0.5 mm depth of cut and 0.1 mm/rev feed rate) with coated carbide tool. It was demonstrated that dry machining with the coated carbide tool leads to potentially acceptable surface quality when using the optimized cutting speed value. Yuan et al. [31] investigated the influence of different cooling methods such as dry, wet, minimum quantity lubrication (MQL) and MQL with cooling air in milling of the Ti–6Al–4V alloy with uncoated cemented carbide inserts. Cutting force, tool wear, surface roughness and chip morphology were experimentally studied to compare the effects of four different cooling air temperatures. Based on the findings, the authors concluded: (1) MQL with cooling air conditions provided lower cutting force, tool wear and surface roughness than those of tests under dry, wet and MQL conditions.

Oktem et al. [19] predicted the minimum surface roughness in end milling mold parts using Artificial Neural Network (ANN) and Genetic Algorithm (GA) approach. Kaya et al. [11] developed tool wear prediction using artificial neural networks (ANN). Choudhury and El-Braadie [4] developed response model for tool life surface roughness and cutting force with central composite method using RSM. They found it very useful for assessing the maximum tool life and surface finish. Rodriguez and Labarga [22] developed an analytical model to predict cutting forces for micromilling operations based on the process geometry. The comparison shows a good agreement between predictions and the experimental measurements.

Kuram et al. [13] studied the optimization of cutting fluids and cutting parameters during end milling by using D-optimal design of experiments. They concluded that the specific energy is largely related to cutting fluid type. Their experimental work shows that Canola cutting fluid (CCF-II) was the best to minimize the surface roughness and specific energy. Xavior and Adithan [29] determined the influence of cutting fluids on tool wear and surface roughness during turning of AISI 304 austenitic stainless steel with cemented carbide tool. Analysis of variance (ANOVA) showed that the feed rate is the influential parameter on surface roughness while cutting speed is influential to tool wear. Importantly, the application of cutting fluid effectively reduced the tool wear and consequently improved the surface finish. Cetin et al. [3] studied the effect of cutting parameters and cutting fluids on surface roughness during turning AISI 304L. They found that the federate is the most influencing factor on surface roughness.

García et al. [10] investigated the effect of cutting parameters and coating of the cutting tool in the surface residual stresses generated by turning AISI 4340 steel. The results indicated that the residual stresses became more tensile due to an increase in cutting temperature, and resulting in detrimental to the surface of the workpiece. They suggested low feed rate, high cutting speed, and non-coated tools with smaller tool nose radius in order to achieve a better surface finish. Malagi et al. [16] investigated the factors influencing cutting forces in turning and reported that cutting force increases as the feedrate and depth of cut increases. Sahin et al. [23] investigated the surface roughness model for machining mild steel with TiN-coated carbide tool. The model was developed in terms of cutting speed, feedrate and depth of cut using response surface methodology. From the results obtained, the authors concluded that surface roughness increases with increasing in feedrate. Conversely, surface roughness decreases with increasing in cutting speed and depth of cut.

Cetin et al. [3] studied the effect of cutting parameters and cutting fluids on surface roughness during turning AISI 304L. They found that the contribution of spindle speed, feedrate, depth of cut and cutting fluids on surface roughness are 0.23%, 97.40%, 0.84% and 0.69% respectively as shown in Table 4. Based on the level of importance of the cutting parameters on surface roughness determined by