EFFECT OF VEGETABLE OIL ON SURFACE ROUGHNESS DURING TURNING OF AISI 1020 STEEL

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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STATEMENT 1

This thesis is the result of my own investigations, except where the otherwise stated. Other sources are acknowledged by giving explicit references.

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ABSTRAK

Kualiti permukaan adalah amat penting untuk menentukan fungsi dan kualiti produk pemesinan. Sebilangan besar kajian telah menggunakan ketinggian purata aritmetik (R_a) untuk menilai permukaan permukaan produk pemesinan, namun didapati berlakunya percanggahan dengan teori kerana parameter ini hanya memberikan amplitud kekasaran di mana maklumat ini adalah tidak mencukupi untuk menilai prestasi pemesinan. Dalam penyelidikan ini, operasi larik bahan kerja yang diperbuat daripada keluli karbon AISI 1020 dilakukan pada kelajuan gelendong yang bervariasi termasuk 1000, 1500, dan 2000 rpm, pada laju umpan tetap 0.20 mm/putaran dan kedalaman potongan 0.5mm. Kaedah dibahagikan kepada pemesinan kering dan basah menggunakan minyak sawit sebagai pelincir pemotongan. Dalam pemesinan kering, nilai R_a, R_t dan R_q turun ketika kecepatan gelendong meningkat daripada 1000 ke 1500 rpm, tetapi kembali bertambah ketika kecepatan gelendong terus meningkat menjadi 2000 rpm. Untuk pemesinan basah, nilai amplitud kekasaran dua kali lebih rendah daripada kecepatan gelendong 1000 dan 2000 rpm, tetapi sedikit lebih tinggi daripada 1500 rpm berbanding dengan pemesinan kering. Analisis korelasi silang juga telah dijalankan untuk penilaian kekasaran dan hasil yang diperoleh hampir serupa. Manakala dengan menggunakan parameter R_{sk} dan R_{ku}, pemesinan basah mengungguli pemesinan kering ketika kedua kecepatan gelendong yang lebih rendah dilaksanakan, tetapi hasilnya bertentangan untuk kecepatan gelendong yang tertinggi. Hasil kajian dapat diringkaskan dimana kaedah kerja larik menggunakan minyak kelapa sawit pelincir pemotongan bergabung dengan parameter proses yang sesuai dapat meningkatkan kualiti permukaan, sementara lebih banyak parameter kekasaran harus digunakan untuk memastikan kebolehpercayaan penyelidikan.

ABSTRACT

Surface quality is vital to determine the functionality and quality of the machined product. Most studies have implemented arithmetic average height (R_a) to evaluate the surface finish of machined product, however deviation from theoretical knowledge was observed as this parameter provides only the vertical amplitude of roughness deviation which was inadequate. In this research, turning operations of workpiece made of AISI 1020 low carbon steel were carried out at varying spindle speeds including 1000, 1500 and 2000 rpm, at constant feed rate 0.20 mm/rev and depth of cut 0.5mm. The machining condition was divided into dry and wet turning using palm oil as cutting fluids. In dry turning, R_a, R_t and R_q values dropped when the spindle speed increased from 1000 to 1500 rpm, but then reversed when the spindle speed was further increased to 2000 rpm. For wet turning, the amplitude roughness values were doubled lower at spindle speed 1000 and 2000 rpm, but slightly higher at 1500 rpm compared to dry turning. Cross-correlation analysis also had been completed for roughness assessment and the result obtained are almost similar. Whereas using R_{sk} and R_{ku} parameters, wet turning outperformed dry turning at both lower spindle speeds, but the result was opposite at the highest spindle speed implemented. The findings can be summarized as turning under palm oil lubricating condition able to improve surface quality in align with suitable process parameters, while more roughness parameters had to be deployed to ensure the reliability of improvements.

CHAPTER 1
INTRODUCTION

1.1 Project Background

Cutting fluid is essential in machining operation, acting as a coolant to reduce heat effect and lubricate at contacting area between tool and workpiece. However, the adverse effects of conventional cutting fluid towards environment and human health are undeniable due to its toxic characteristics. Research communities are making utmost effort to explore eco-friendly alternative, for instance utilization of vegetable oil. This biodegradable oil offers several advantages include lower cost, ease of availability and renewable. Palm oil is an example of vegetable oil, its high saturated fatty acids content (50%) causes it less favorable in cooking which will lead to cardiovascular disease (Goon et al., 2019). In contrast, palm oil possesses better candidate to replace mineral-based cutting fluid due to the polarities of fatty acids promote formation of lubricant film between tool-workpiece interface, thus reducing friction and wear, subsequently improving surface quality of manufactured workpiece (Debnath, Reddy, & Yi, 2014). Moreover, minimum quantity lubrication (MQL) was highly advocated during the application as moving towards green and sustainable manufacturing (Ivanova et al., 2016).

However, researchers mostly deployed average surface roughness, R_a to evaluate the improved performance in surface integrity brought by vegetable oil-based fluids. In fact, R_a does not provide sufficient information about surface profile, such as slope, shape, size and distance between asperities. Figure 1-1 clearly depicts the drawback of this measurement technique, it can be seen that various surface profiles are having the same R_a value.

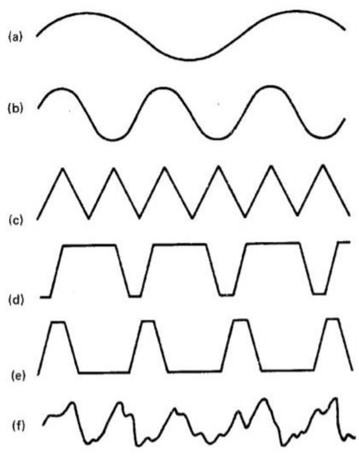


Figure 1-1: Various surface profiles but with same R_a value (Bhushan, 2000)

Therefore, the present work will emphasize on investigating the effects of adding palm oil during turning on surface roughness, by applying different amplitude roughness measurement techniques to ensure the reliability of findings. During the experimental works, in order to achieve optimal machining quality, several spindle speeds will be tested whereas the rest of the machining and lubrication parameters are remained constant.

1.2 Problem Statement

Surface integrity is imperative to determine the functionality and quality of the machined product, hence often cutting fluid is used as lubrication during the machining process to improve its performance. However, conventional lubricant brings adverse effect to the environment in terms of pollution. One of many solutions is replacing with vegetable oil. In most cases, the existing studies have deployed average surface roughness (R_a) measurement to evaluate the turning performance using vegetable oil as lubricant. Nevertheless, this method reliability is in doubt due to lack of providing surface profile information and the findings deviated from the theory. For instance, several results in the literature reviews conducted have recorded that higher flank wear but lower surface roughness in machined workpiece. Therefore, present study emphasizes to analyze the machined surface through different amplitude surface roughness parameters as well as cross-correlation method to justify that vegetable oil is a great alternative for conventional cutting fluid in machining.

1.3 Objective

1. To evaluate the effect of utilizing palm oil as cutting fluids in turning on the surface roughness of machined workpiece
2. To investigate the feasibility of measurement techniques for surface roughness analyzing for ensuring the reliability of findings

1.4 Scope of Research

In this project, surface roughness of the machined workpiece in dry and wet turning using conventional lathe machine will be assessed. To be mentioned, the lubricant applied in wet turning is palm oil. Process parameters including spindle speed is the variable in the experimental procedure whereby feed rate, depth of cut and lubrication condition are maintained constant. Roughness parameters include arithmetic mean surface roughness (R_a), total height of the roughness profile (R_t), root mean square roughness (R_q), skewness (R_{sk}) and kurtosis (R_{ku}) as well as cross-correlation of profile between four different sides of machined workpiece are among the evaluation criteria. Each outcome is judged on its feasibility and the most convincing parameter will be concluded and further justified.

The surface profile is captured using high resolution camera and subsequently the images are being processed in MATLAB software before further analysis at the same platform. The developed simulation program will be validated with roughness measuring instrument to ensure its accuracy and reliability.

1.5 Thesis Organization

The thesis structure is divided into five chapters. First chapter is introduction about project research background, problem statement, objective and scope of research. The purpose and direction of this project are defined in this chapter. Secondly, related works from other researchers with regards to effect of utilizing vegetable-based cutting fluid on the turning quality and different roughness measurement techniques adopted are being studied. The useful findings and their limitations are extracted to support and enhance this project research. In the third chapter, research methodology which is partitioned into experimental preparation and procedure as well as surface roughness measurement simulation will be outlined in detail. Then the results will be recorded in 4^{th} chapter, and the variations in machining performance between dry and wet turning besides feasibility of roughness measurement technique are further discussed. Last chapter will be presenting the summary of findings and recommendations in the future approach.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of the works accomplished by previous researchers with regard to surface roughness evaluation in workpiece turning. The first section focuses on the application of vegetable oil as lubricants and its effects on the surface roughness. Next, spindle speed as the variable machining parameter is being investigated on its impacts towards the surface integrity. Thereafter is the assessment of viability and sustainability of different surface roughness measurement techniques being implemented. The extracted useful information from the previous works is summarized at the end of this chapter.

2.2 Application of Vegetable-based Cutting Fluid and Its Effects on Surface Roughness in Turning

Cutting fluids are beneficial to the industry players, it promotes improved machining quality and tool life besides allowing use of higher cutting speed and feed rate by limiting machine overheats. However, mineral-based cutting fluids contaminated with metal particles and degradation substances lead to human health and environmental issues. On the other hand, vegetable-based metal cutting fluids are drawing attention in the industries as the effective alternative to the former cutting fluid type, attributing to its characteristics of renewable, biodegradable, non-toxic and having comparable performance to the conventional cutting fluids. In the most recent years, rapid research relevant to the usage of vegetable oils and the associated turning quality has been carried out.

Kazeem et al. (2020) investigated the application of a less known vegetable oil, Jatropha oil in turning of AISI 1525 alloy steel. Jatropha oil achieved lower cutting temperature and surface roughness as well as better tool life compared to mineral-based cutting fluid through the formation of thin lubrication film at the tool-workpiece interface during machining. Chinchanikar et al. (2014) evaluated the surface roughness in turning of hardened AISI 52100 steel under dry and coconut oil as cutting fluid condition. The experimental results indicated that at higher cutting speed, feed and depth of cut, coconut oil emerged to be more capable of reducing surface roughness of machined workpiece.

Sankaranarayanan et al. (2021) reviewed that vegetable oils promised superior performance in machining applications due to its adsorption property facilitates the frictional dissipation and able to generate a lubrication layer at the contacting surfaces. Implementation of this bio-friendly metal cutting fluids is in line with the strategies of green machining. Ghatge et al. (2018) justified that turning of duplex stainless steel using vegetable-based cutting oil such as coconut oil and neem oil yielded improvements on tool wear and average surface roughness value.

Majak et al. (2020) studied the suitability of vegetable oils as lubricants in turning of AISI 304 stainless steel at minimum lubrication quantity (MQL). Among the various vegetable oils used, sunflower oil found to have better performance in terms of surface roughness and chip compression ratio. Cetin et al. (2011) examined the use of different vegetable-based cutting fluids in turning of AISI 304L stainless steel for reducing of surface roughness, cutting and feed forces. The results implied that sunflower and canola oil outperformed the others, in addition lowering the occupational health risks and waste treatment expenses because of its biodegradable properties.

2.3 Influence of Cutting Speed on Surface Roughness in Turning

Turning is a machining process of rotating workpiece at high speed and a cutting tool moves linearly to complete the material removal process. The workpiece is clamped to a lathe chuck, the spindle speed is one of the deciding factors for surface quality of output. Patel et al. (2019) conducted analysis on surface roughness variation based on machining variables like feed rate, cutting speed and tool nose radius in turning of AISI D2 steel using cubic boron nitride (CBN) tool. The researchers reported that surface roughness decreased with increasing the cutting speed from 80 m/min to 152 m/min, using constant feed of 0.04 mm/rev and 1.2mm tool nose radius. Dhananchezian (2021) carried out dry turning operation of Inconel 600 using titanium aluminum nitride (TiAlN) carbide insert at different cutting velocities. It was observed that initially R_a value decreased with the increasing cutting velocity due to temperature rise favored the deformation of workpiece. However further increase in the parameter deteriorated the surface finish. The optimal cutting velocity was 102 m/min with the lowest surface roughness value generated and absence of chip adhesion at tool point after turning.

Vijaya Ganesa Velan et al. (2020) investigated the effects of cutting parameters on forces and surface roughness in turning AISI 1045 steel. The study revealed that the feed was the dominant factor, which its relationship to the cutting force and surface roughness was directly proportion. Whereas cutting speed had inversed relationship due to the heat produced at the tool-workpiece interface tended to soften the material, hence the reduction of shear force. Zheng et al. (2018) explained that three cutting forces were involved during turning, they are radial force, tangential force and feed force which the last mentioned is the primary component. In accordance with the increase of cutting speed, the amplitude of these forces and cutting temperature also became higher.

Oschelski et al. (2021) analyzed the effect of three input parameters: Cutting speed, depth of cut and lubricating condition on surface roughness in finish turning of Hastelloy X superalloy. The findings were lower cutting speed and larger depth of cut generated unsatisfactory R_a values due to chatter vibration. Kumar Sahu et al. (2021) determined that high spindle speed resulted in lower main cutting force whilst higher temperature at the cutting zone. These two phenomena were closely related as temperature rise induced plastic deformation thus softening of workpiece and less cutting force was demanded. Besides, higher cutting speed eliminated the built-up edge (BUE) formation therefore the surface finish was enhanced.

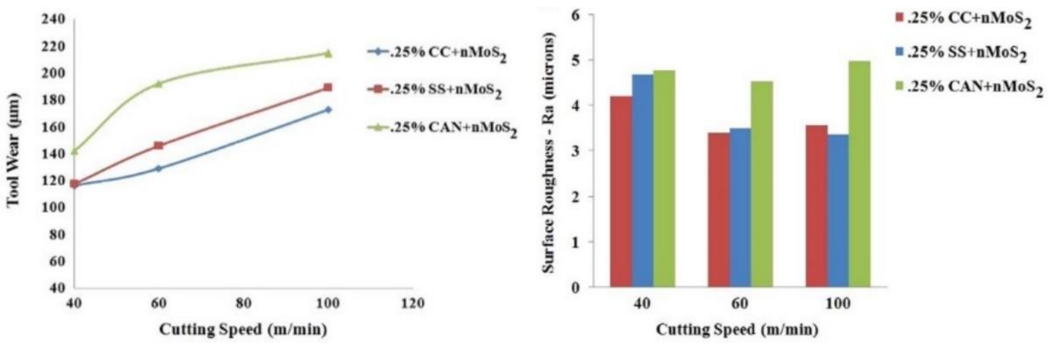
Kumar et al. (2021) studied the application of two vegetable-based machining fluids: Cotton seed and groundnut, in turning operation of EN 24 steel. The conclusion included decrease in surface roughness with increasing of cutting speed. Whereby Gunjal et al. (2018) deduced that surface roughness was rarely affected under varying cutting speed, as feed rate was maintained constant throughout the turning of hardened AISI 4340 steel using canola, coconut and soybean oils at MQL.

Liu et al. (2021) reported that increase in cutting speed within an allowable range able to reduce vibrations and surface roughness in minimum quantity cooling lubrication (MQCL) turning of stainless steel. The axial and radial cutting resistance decreased at higher cutting speed since more heat produced to soften the material hence lower cutting forces were required. Nevertheless, exceeding the largest range the axial vibration became more significant, simultaneously the surface chatter frequency exhibited the same trend. Furthermore, higher cutting speed shortened cutting time therefore the number of tool wrinkles on the workpiece surface minimized. Chinchanikar et al. (2013) pointed out turning at higher cutting speed resulted in reduction of the shear strength of work material, thus lowering the cutting forces and surface roughness.

2.4 Application and Feasibility of Surface Roughness Measurement Technique

Surface roughness evaluation is vital for many fundamental analyses such as positional accuracy, friction, contact joints and deformation. In general, surface roughness parameters can be categorized into three groups including amplitude, spacing and hybrid parameters. The accuracy of different roughness parameters has always been the subject of experimental and theoretical investigations among researchers.

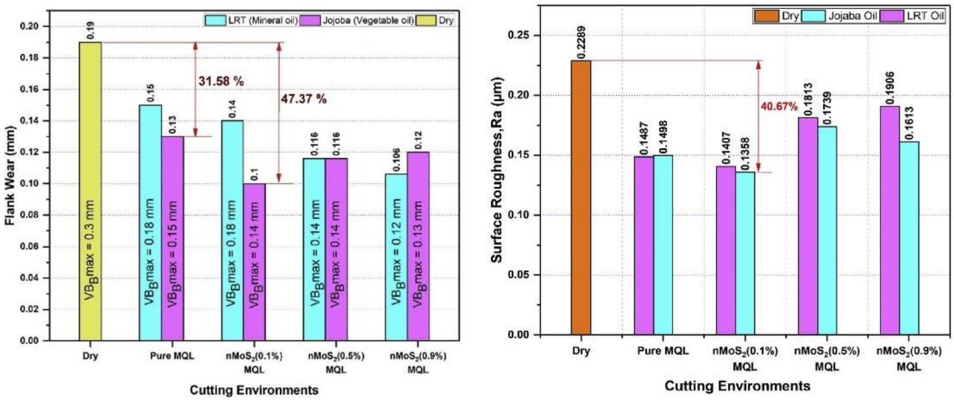
Padmini et al. (2016) examined the turning performance of AISI 1040 steel using coconut, sesame and canola oils at MQL with varying dispersions of nano-molybdenum disulphide ($nMoS_2$). It was observed that coconut oil mixed with 0.5% $nMoS_2$ exhibited better machining performance in terms of lower cutting force, temperature, tool wear and surface roughness compared to dry machining. However, abnormality can be found which increasing of cutting speed accelerated tool wear but generating lower R_a, as illustrated in Figure 2-1. Tool flank wear showed an increasing trend along with higher cutting speed, by contrast, R_a result was fluctuating.



(a) (b)

Figure 2-1: (a) Variation of tool flank wear with cutting speed. (b) Variation of R_a with cutting speed (Padmini et al., 2016).

Using the same nanoparticle as above, Gaurav et al. (2020) assessed the jojoba oil as a pure and nano-fluid based oil in hard-turning of Ti-6Al-4V at MQL. The results showed that jojoba oil with an optimum concentration of $nMoS_2$ was a sustainable replacement for mineral-based oil by reducing cutting force, surface roughness and tool wear. These improvements attributed to the long chain fatty acidic structure of jojoba oil, besides excellent thermal oxidative stability and high viscosity index. Similar abnormality also observed in which higher flank wear gave rise to lower R_a. In figure 2-2, at pure MQL, jojoba oil recorded lower flank wear compared to mineral-based oil but the R_a result was opposed. Whereas at MQL with 0.9% concentration of $nMoS_2$, higher flank wear but lower R_a were obtained in jojoba oil as compared to mineral-based oil.



(a) (b)

Figure 2-2: (a) Variation in flank wear under different cutting fluid environments. (b) Variation in R_a under different cutting fluid environments (Gaurav et al., 2020).