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Examining the Effect of Various Vegetable Oil-Based Cutting Fluids on Surface Integrity in Drilling Steel – A Review

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Abstract. Increased attention on environmental and health impacts by industrial activities forces the manufacturing industry to reduce the mineral oil-based metalworking fluids as a cutting fluid. The advantages of using vegetable oil-based cutting fluids on tool wear and the cutting force have been reported in the literature, but those reporting the effects of their use on the surface finish of the workpiece are still lacking. This mini-review gives an overview of the influence of vegetable oil-based cutting fluids on surface integrity of steel during drilling process. Effect of the different cooling strategies on surface integrity is also presented.

Introduction

Cutting fluids have commonly been viewed as a required addition to high productivity and high quality machining operations [1]. However, the negative effects of conventional cutting fluids on the manufacturing cost, human health, and environment have motivated many researchers to look for alternative coolant in replacing the excessive use of mineral and synthetic cutting fluids. Cutting fluids are contaminated with metal particles. A number of negative effects on health that can be caused by the use of metal working fluid such are toxicity, dermatitis, respiratory disorders and cancer [2] as well as sensory and respiratory irritation, skin irritation and skin abrasions, potential carcinogenesis and impaired pulmonary function [3]. When inappropriately handled, cutting fluids may also damage soil and water resources, causing serious loss to the environment [4].

Due to growing environmental concerns, vegetable oils are finding their way into coolants and lubricants for industrial applications. Numerous studies have been conducted on machining of stainless steel in order to evaluate vegetable-based cutting fluids such as rapeseed oil [5], coconut oil [6-7], sunflower oil [8-9], canola oil [10-11], palm oil [12], and castor oil [8, 13]. Use of vegetable oil as cutting fluids has displayed excellent performance due to good lubrication property, high viscosity index, renewability, non-toxicity, and better biodegradability [14].

Surface integrity in the engineering sense can be defined as a set of various properties (both, superficial and in-depth) of an engineering surface that affect the performance of this surface in service. These properties include surface finish, texture, and profile, fatigue corrosion and wear resistance, and adhesion and diffusion properties among others [15].

Different workpiece material with different properties and microstructure gives different effect during machining, including drilling. Steels, the common workpiece for machining, are of interest Despite being common process, drilling of steels are challenging. Drilling of stainless steel is considered difficult due its unfavorable properties when subjected to machining such as gummy, high strength, high modulus of elasticity and so on. These properties were responsible for the rapid wear on the cutting tool hence resulting in short tool life and rapid tool failure [16]. Microhardness of hardened steel is the main factor in abrasive wear to the tool [17]. At the same time, it is necessary to meet the surface integrity requirements, where tool wear can lead to residual stress and poor surface roughness in the machined surface [18].

This paper reviews and identifies the effect of vegetable oil-based cutting fluids on surface integrity of steels, included stainless steel during drilling operations.

Recent Findings on Surface Integrity Assessment

Kuram et al. [8] studied surface roughness and thrust force in drilling of AISI 304 stainless steel using vegetable based cutting fluids developed from crude sunflower (CSCF) and refined sunflower oil (SCF) as cutting fluids. The cutting fluids were developed in form of CSCF-I (20% Tween85 surfactant with viscosity of 1.7 cp at 40°C), SCF-I (20% Tween20 surfactant with viscosity of 1.9 cp at 40°C) and SCF-II (20% Tween20 and 15% Tween85 surfactants with viscosity of 1.3 cp at 40°C) and a commercial mineral cutting fluid (termed as CMCF) as reference. Their finding is as depicted in Fig. 1(a & b). In Fig. 1 (c & d)), other result presented by Ozcelik et al. [9] when studying surface roughness optimization during drilling AISI 304 stainless steel using two different vegetable oils. Cutting fluids from refined sunflower oil were developed, i.e.. VCF-1 (20% Tween85 surfactant, viscosity of 1.5 cp at 40°C) and VCF-2 (20% Tween85 and 9% Peg400 surfactants, viscosity of 1.1 cp at 40°C). Mineral based cutting fluid (MCF) and semi synthetic cutting fluid (SSCF) were used as reference [9].

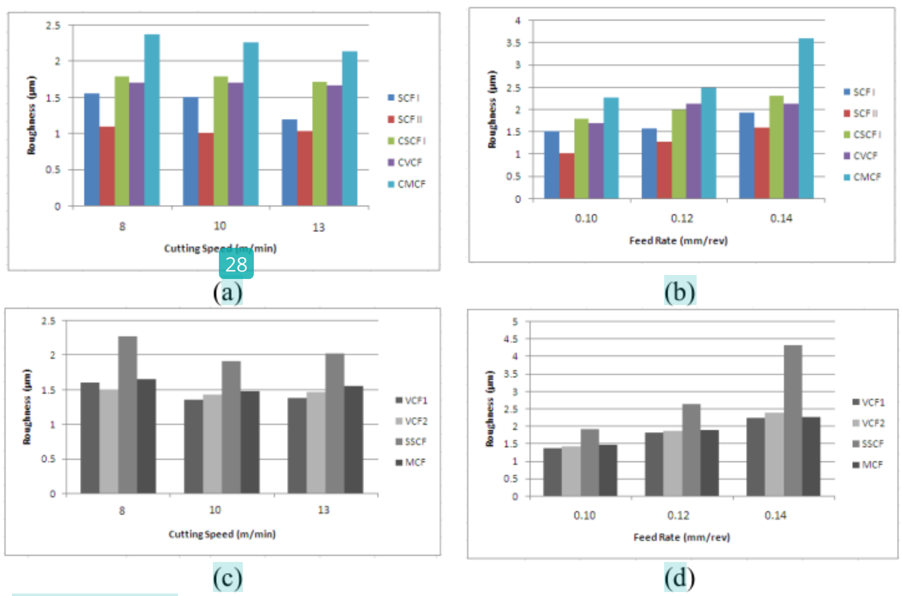

Fig. 1. The effect of vegetable oil on surface roughness at various drilling parameters [8,9].

According to their findings, the lowest of 1.01µm and highest of 2.26µm of surface roughness were achieved at using SCF-II and CMCF, respectively, using the same cutting conditions (Fig. 1a.). Compared to SCF-I, SCF-II gave finer surface roughness for all cutting conditions, which might be related to difference in viscosity. Viscosity affects the flow of cutting fluid. So, cutting fluid with low viscosity expectedly can reach the tool-workpiece interface more effectively, making chips to be flushed away from the cutting zone and preventing a finished drilled hole surface from becoming scratched [19].

Related to surface roughness, minimum value of 1.36µm were obtained by using vegetable based cutting fluid VCF-1, followed by VCF-2 with 1.43µm, CMCF with 1.48µm, and being maximum of 1.92µm by SSCF (Fig. 1c.). VCF-1 produced better surface roughness compared to VCF-2 although the former has higher viscosity. This can be attributed to the lubrication ability, in which cutting fluid with low viscosity has poor lubricating capability [19]. This result hinted that there is a critical cutting fluid viscosity value that can give the best surface roughness out of this AISI 304 workpiece.

From the same reports [8,9], analysis of variance (ANOVA) results for surface roughness are shown in Table 1. It can be seen that cutting fluid, feed rate and cutting speed have significant effect on surface roughness of the workpiece. It can also be derived from the ANOVA results that the cutting fluid has no interaction effect to both cutting speed and feed rate since its mean square error is less than mean square error of cutting speed and feed rate.

Table 1. Summary of ANOVA for cutting fluid on surface roughness (a) [8] and (b) [9]

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Cutting Speed	1.1184	2	0.5592	9.9681	0.0067	4.459
Cutting Fluid	3.6366	4	0.9091	16.2052	0.0007	3.8379
Error	0.4488	8	0.0561			
Total	5.2038	14				
Feed Rate	0.0605	2	0.0303	4.8057	0.0426	4.459
Cutting Fluid	2.4055	4	0.6014	95.5003	8.71E-07	3.8379
Error	0.0504	8	0.0063			
Total	2.5164	14				

(a)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Cutting Speed	0.0930	2	0.0466	11.5389	0.0088	5.1433
Cutting Fluid	0.7798	3	0.2599	64.4879	5.89E-05	4.7571
Error	0.0242	6	0.0040			
Total	0.8970	11				
Feed Rate	3.2490	2	1.6245	9.5898	0.0135	5.1433
Cutting Fluid	2.7572	3	0.9191	5.4254	0.0382	4.7571
Error	1.0164	6	0.1694			
Total	7.0227	11				

(b)

For another type of steel, Kilickap et al. [20] evaluated the surface roughness of AISI 1045 steel during drilling using different cooling strategies. Fig. 2 shows comparison of the roughness values on the hole wall at different cooling condition. Minimum quantity of lubrication (MQL) tends to result fine surface roughness values (Ra of 3.04µm) compared to dry drilling (Ra of 3.48µm) at the same drilling parameters. The general trend was when cutting speed increases, surface roughness value decreases. Contrasting trend that higher cutting speed causes an increase in surface roughness was perhaps due to the increasing tool wear when higher machining speed was employed [21].

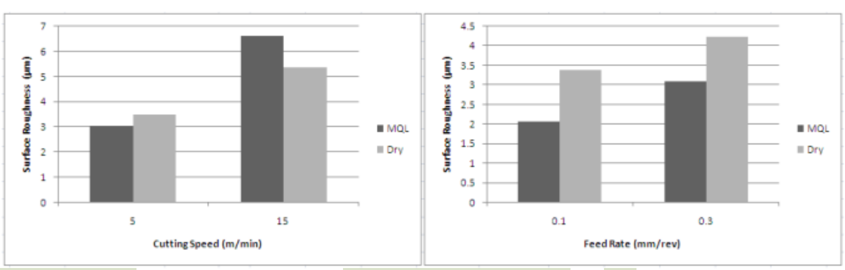

Fig. 2. The effect of the drilling parameter on surface roughness at the different cooling system [20].

In another study, Brandao et al. [22] evaluated the hole quality of AISI H13 during drilling using different cooling strategies. The authors used vagetable oil based cutting fluid, termed BioG 850and evaluated the hole quality. Fig. 3a shows comparison of the roughness values on the hole wall at different cooling conditions. MQL tends to result low roughness surface values at lower cutting speed of 25 m/min, while the flood cooling shows low surface roughness when cutting speed is 60 m/min. Use of dry coolant system shows similar result for both cutting speeds tested.

Regarding diameter error, It was reported thatt flooded cooling and MQL technique produced the same results [22]. It was the dry system that shows the largest diameter error [22]. High cutting speed was proven to be better at reducing diameter error (Fig. 3b.) [22]. Based on the experiments, with cutting speed of 60 m/min, it was concluded that cooling technique is of great influence on cylindricity error where lowest (2μm) error was given by flood cooling system, followed by dry drilling (2.5μm), and MQL drilling (4μm) (Fig. 3c.) [22]. For circularity error, MQL has the worst performance, for instance at the cutting speed of 60 m/min, with 6μm compared to 3.5μm using dry drilling and 0.75μm resulted by flood cooling (Fig. 3d.) [22]. It seems that MQL is an effective method to lubricate tool-workpiece interface, but it is not an effective way to cool down cutting zone temperature [23].

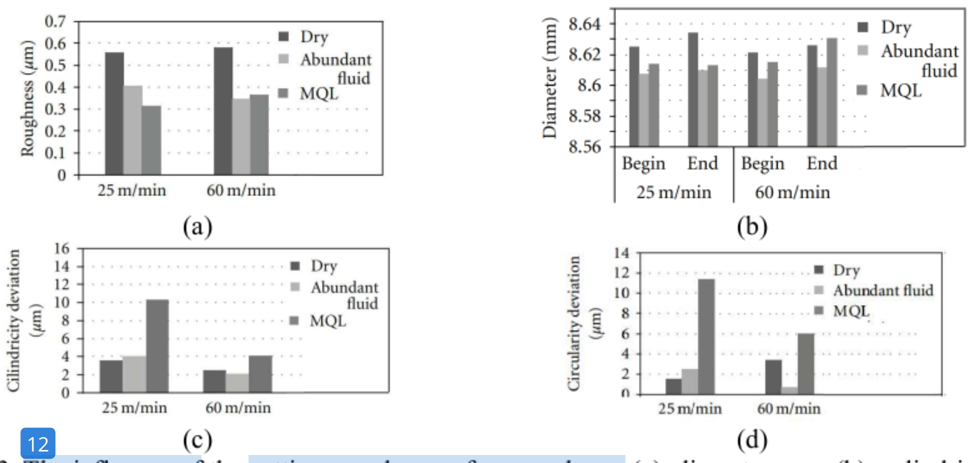

Fig. 3. The influence of the cutting speed on surface roughness (a), diameter error (b), cylindricity error (c), and circularity error (d) at the different cooling strategies [22].

Concluding Remarks

This mini review studies the influence of vegetable oil-based cutting fluids on surface finish of steel workpiece during drilling operation. It was found that cutting fluid, feed rate, and cutting speed have significant effect on surface roughness of the steel (AISI 304). In terms of surface roughness, MQL technique outperforms dry and conventional wet cutting. Surface roughness of austenitic stainless steel being processed by drilling using vegetable oil-based cutting fluids was very fine. At particular process parameters selected, the resulting Ra was entirely below the finish machining process threshold of 1.6 μm [24]. Literatures on effects of vegetable oil-based cutting fluids for other surface integrity, such as hole size enlargement, chip formation, cap formation, burr height, microhardness variation and residual stress are still lacking. Considering its advantages and also inconsistence due to viscosity effect on surface roughness, further research on drilling of steels is worth pursuing in search of better machining responses using alternative cutting fluids.

Acknowledgements

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