Effects of the Cutting Fluid Types and Cutting Parameters on Surface Roughness and Thrust Force

E. Kuram, B. Ozcelik, E. Demirbas, and E. Şık

***Abstract*- In this study, three different vegetable-based cutting fluids developed from raw and refined sunflower oil and two commercial types (vegetable and mineral based cutting oils), were carried out to determine for thrust force and surface roughness during drilling of AISI 304 austenitic stainless steel with HSSE tool. The uses of vegetable cutting oils was investigated in reducing thrust force and improve surface finish at different spindle speeds and feed rates during drilling. In the experiments, spindle speed, feed rate and drilling depth were considered as machining parameters.**

***Index Terms*- Drilling, Thrust force, Surface roughness, Cutting fluids, Vegetable based cutting fluids.**

I. INTRODUCTION

The use of cutting fluids in metal cutting was first reported in 1894 by F. Taylor who noticed that cutting speed could be increased up to 33% without reducing tool life by applying large amounts of water in the cutting zone [1]. Cutting fluids increase the tool life and improve the efficiency of the production systems providing both cooling and lubricating the work surface.

Cutting fluids are extensively used in drilling operations as it removes chips from inside the holes, thus preventing drill breakage [2]. Higher surface finish quality and better dimensional accuracy are also obtained from cutting fluids [3]. Many types of cutting fluids namely, straight oils, soluble oils, synthetic and semi synthetic are widely used in metal cutting processes. Bio-based cutting fluids have the potential to reduce the waste treatment costs due to their inherently higher biodegradability and may reduce the occupational health risks associated with petroleum-oil-based cutting fluids since they have lower toxicity. The output is a healthier and cleaner in the work environment, with less mist in the air.

For that reason, cutting fluids developed from vegetable oil in the present study are environmentally friendly and have a good lubricating ability as compared to others [4]. There are not many studies presented about vegetable based cutting oils in the literature. Belluco and De Chiffre [5] investigated effect of vegetable based cutting oil on cutting forces and power. AISI 316L stainless steel workpieces were machined with drilling, core drilling, reaming and tapping using HSS-E tools. From the comparison of performance results obtained from two cutting fluids showed that the vegetable based cutting oils were better than the commercial mineral oil. Belluco and De Chiffre [6] improved formulations of vegetable oils which used as comparison with a mineral oil on surface integrity and part accuracy in reaming and tapping operations with AISI 316L stainless steel. The results with the new formula were better than that of mineral oil. Later on De Chiffre and Belluco [7] used three vegetable based cutting oils including EP additives and a straight cutting fluid for performance study in turning, reaming and tapping operations. Results indicated that vegetable based cutting oils were superior to mineral oil. Belluco and De Chiffre [8] evaluated the performance of six cutting fluids (a commercial mineral oil, and five vegetable-based cutting fluids) in drilling AISI 316L stainless steel using conventional HSS-Co tools. Tool life, tool wear, chip formation and cutting forces were studied as performance criteria and results were better with vegetable cutting oil than that of the mineral cutting fluid because tool life was increased by 177% and thrust force was reduced by 7%. Xavior and Adithan [9] studied performance of coconut oil during the machining of AISI 304 material with carbide tool. They found that coconut oil reduced the tool wear and improved the surface finish with respect to mineral oil. Kuram [10] investigated effects of developed vegetable based cutting fluids (VBCFs) and cutting parameters on thrust forces and surface roughnesses in the drilling of AISI 304 stainless steel. Ozcelik et al [11-13] reported the effect of MCFs developed from vegetable based cutting oils (VBCFs) and other commercial MCFs on thrust force and surface roughness when drilling of AISI 304 stainless steel.

In this study, the effect of cutting fluids developed from raw and refined sunflower oil and two other commercial cutting fluids were evaluated for thrust force and surface roughness during drilling of AISI 304 stainless steel.

II. EXPERIMENTAL SETUP

A. Vegetable based cutting fluid

The cutting fluid consisted of a vegetable oil (refined sunflower oil) as base oil and additives. It was an oil-in-water emulsion type which contained a surfactant mixture (Tween 85 and Peg 400, Merck), and various additives in

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TABLE I
CHARACTERIZATION OF VEGETABLE BASED CUTTING FLUIDS

Metal cutting fluid*	pH (Emulsion 8%)	Density (g/ml)	Viscosity 40 °C (mm^2/sec)	Viscosity, 40 °C (mm^2/sn) (Emulsion 8%)	Flash point (°C)	Refractive index
CSCF-I	8.70	0.970	71	1.4	218	1.475
SCF-I	9.10	0.980	74	2.0	199	1.474
SCF-II	9.00	0.975	75	1.9	170	1.475
CVCF	9.32	0.960	85	1.5	205	1.476
CMCF	9.40	0.906	29	1.4	175	1.482

*CSCF-I: Crude sunflower cutting fluid; SCF-I: sunflower cutting fluid ; SCF-II: sunflower cutting fluid (a mixture of two surfactants); CVCF: Commercial vegetable cutting fluid; CMCF: Commercial mineral cutting fluid.

the formula to meet the specifications such as resistance to bacterial growth, corrosion, antifoaming agent and antiwear [10]. The additive concentrations used were below 10% w/w. An emulsion is a dispersion of one immiscible liquid into another, through the use of a chemical reagent that reduces the interfacial tension between the two liquids to achieve stability. The appearance of the emulsion was that of a homogenous liquid with 100 µm size of droplets in the dispersion. Water content in the cutting fluid varied depending on the source, but the cutting fluid in the present study contained 92% water. Two different vegetable cutting oils from refined sunflower oil were developed using a surfactant (Tween 85) and a mixture of two surfactants (Tween 85 and Peg 400). Characterization of vegetable cutting oils was shown in Table 1.

B. Drilling conditions and experimental design

In this study, spindle speed, feed rate and drilling depth were considered as machining parameters. Drilling experiments were carried out with all cutting fluids at different spindle speeds and feed rates. Two experimental designs were used. At first experiment, effect of spindle speeds (520, 620 and 720 rpm) was investigated at a constant feed rate of 0.12 mm/rev and drilling depth of 21 mm. At second experiment, effect of feed rates (0.08, 0.12, 0.16) was investigated at a constant spindle speed of 620 rpm and drilling depth of 21 mm.

C. Cutting fluids, workpiece materials and cutting tools

Five cutting fluids, namely bio and mineral based commercial cutting fluids and vegetable-based cutting fluids developed from sunflower oil were used in this study. 6.4 l/min was used for all cutting fluids as a flow rate. The drilling experiments were carried out on a DECKEL MAHO DMU 60 P five axis CNC milling machine equipped with a maximum spindle speed of 12000 rpm and a 15 kW drive motor. DIN 338 HSSE 130º Silver Series drill (8 mm in diameter and 117 mm in length) was used as a cutting tool.

AISI 304 austenitic stainless steel with a Vickers hardness of 300 was used as a workpiece material. The dimension of workpiece was 160 mm x 100 mm x 30 mm. The chemical composition of workpiece was given in Table 2.

D. Thrust force measurement

The drilling forces were measured with a Kistler 9257B type dynamometer. Force data was saved on a personal computer, acquired via a DAQ Card and Dynoware software.

E. Surface roughness measurement

Surface roughness was measured with a Mitutoyo Surf Test 301. At the surface roughness measurements, cut-off length and number of sampling lengths were selected 0.8 mm and 3, respectively. This measurement was repeated two times, the average value was used for analysis. Measurement processes were made in parallel with drilled axis.

TABLE II
THE CHEMICAL COMPOSITION OF WORKPIECE MATERIAL

AISI 304 (%)				
C	Si	Mn	P	S
0.0340	0.6400	1.8900	0.0410	0.0130
Cr	Ni	Mo	Cu	Co
18.7500	8.2300	0.3980	0.6900	0.1050
Fe				
69.0000				

III. RESULTS

A. Thrust force results

Fig. 1 shows the effect of spindle speed and cutting fluid type on thrust force using a feed rate of 0.12 mm/rev and drilling depth of 21 mm.

An increase in the spindle speed decreased the thrust force value since under higher cutting velocities, the tool would cut better without ploughing, resulting in a drop in thrust force. Under smaller cutting velocities, the tool would have a tendency to plough on the workpiece, resulting higher thrust force. This result was in consistent with the literature [15-17]. Lower thrust force values were obtained with SCF-I and the least thrust force was achieved at spindle speed of 720 rpm. SCF-I generated the highest reduction in thrust force when AISI 304 stainless steel drilled at a feed rate of 0.12 mm/rev and a drilling depth of

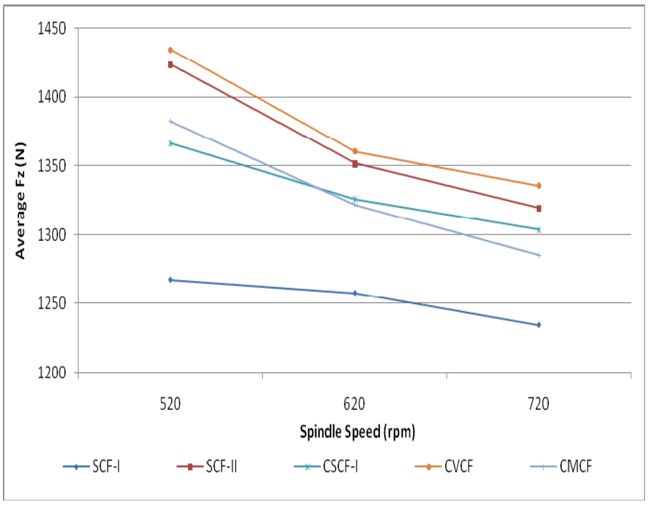

Fig. 1. The effect of spindle speed and cutting fluid type on thrust force.

21 mm.

Fig. 2 shows the effect of feed rate and cutting fluid type on thrust force using a spindle speed of 620 rev and drilling depth of 21 mm.

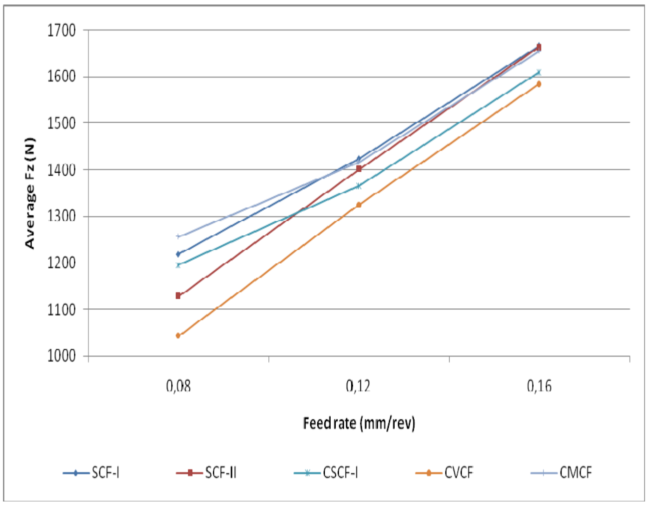

Fig. 2. The effect of feed rate and cutting fluid type on thrust force.

At low feed rate, the thrust force of the hole was decreased. An increase in the feed rate increased the thrust force value since an increase in feed rate increased the materials removal rate, consequently more energy was required. This caused an increase in the thrust force. This result was in consistent with the literature [16, 18-19]. The variation in thrust force with feed rate when AISI 304 stainless steel was drilled was not noticeable for cutting fluids at feed rate more than 0.12 mm/rev (Fig. 2). However, at 0.08 mm/rev the difference in the thrust force was visible. The Fig. 2 showed that when AISI 304 stainless steel was drilled, CVCF had low thrust force and the least thrust force was achieved at feed rate of 0.08 mm/rev.

B. Surface roughness results

Fig. 3 shows the effect of spindle speed and cutting fluid type on surface roughness using a feed rate of 0.12 mm/rev and drilling depth of 21 mm.

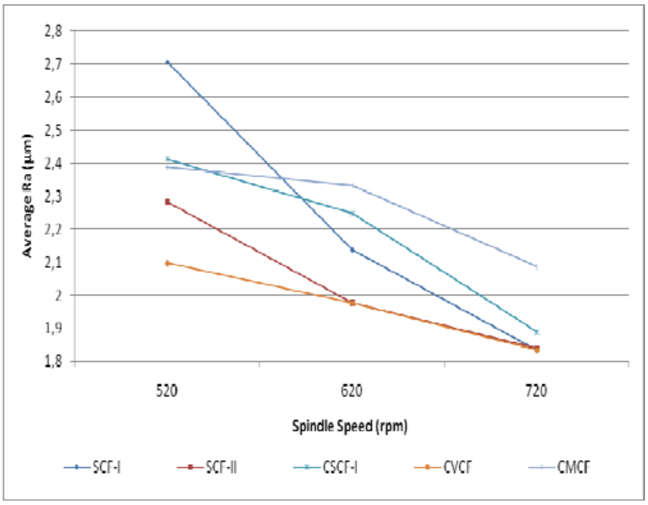

Fig. 3. The effect of spindle speed and cutting fluid type on surface roughness.

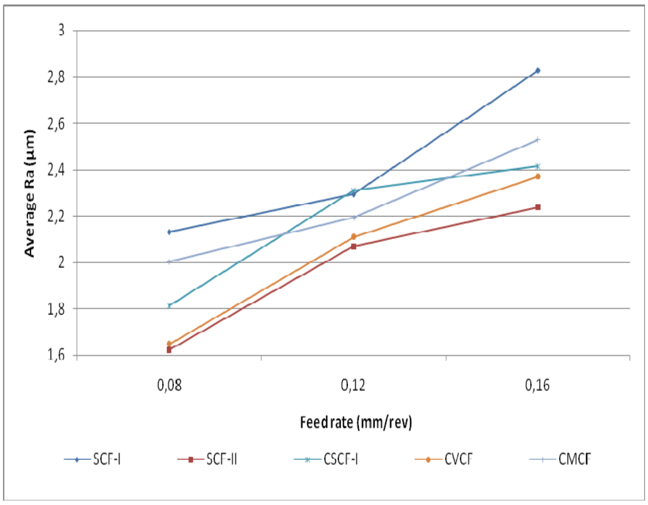

Fig. 4. The effect of feed rate and cutting fluid type on surface roughness.

An increase in the spindle speed decreased the surface roughness value. High spindle speeds reduce forces and vibration, giving better surface finish. This result was in consistent with the literature [15, 16, 20, 21]. The least surface roughness was achieved at spindle speed of 720 rpm using CVCF. SCF-I was the most effective in reducing surface roughness as spindle speed increased. By increasing

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the spindle speed from 520 rpm to 720 rpm the surface roughness was decreased by up to 32% for SCF-I.

Fig. 4 shows the effect of feed rate and cutting fluid type on surface roughness using a spindle speed of 620 rev and drilling depth of 21 mm.

An increase in the feed rate increased the surface roughness value since an increase in feed rate increased the materials removal rate. This result was in consistent with the literature [15, 16, 20, 21]. Fig. 4 showed that SCF-II and CVCF had low initial surface roughness at feed rate of 0.08 mm/rev. SCF-II had the smallest surface roughness at feed rates lower than 0.12 mm/rev, therefore, it was found that SCF-II is superior at the lower feed rates. The least surface roughness was achieved at feed rate of 0.08 mm/rev using SCF-II.

IV. CONCLUSIONS

The evaluations of cutting fluids with respect to thrust force and surface roughness measurements were determined and the obtained results from the vegetable based cutting fluids were compared with the commercial cutting fluids. The following conclusions were drawn from the analysis of the results:

- Lower thrust force values were obtained with SCF-I and the least thrust force was achieved at spindle speed of 720 rpm. SCF-I generated the highest reduction in thrust force when AISI 304 stainless steel drilled at a feed rate of 0.12 mm/rev and a drilling depth of 21 mm.
- When AISI 304 stainless steel was drilled, CVCF had low thrust force and the least thrust force was achieved at feed rate of 0.08 mm/rev.
- The least surface roughness was achieved at spindle speed of 720 rpm using CVCF. SCF-I was the most effective in reducing surface roughness as spindle speed increased.
- SCF-II had the smallest surface roughness at feed rates lower than 0.12 mm/rev. The least surface roughness was achieved at feed rate of 0.08 mm/rev using SCF-II.
- An increase in the spindle speed decreased the thrust force value.
- An increase in the spindle speed decreased the surface roughness value.
- An increase in the feed rate increased the thrust force value.
- An increase in the feed rate increased the surface roughness value.
- Tool wears were not observed with all cutting fluids.

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