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Application of Castor Oil-based Cutting Fluids in Precision Turning

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Abstract: Green machining is a process that implements sustainable development strategy. In order to reduce cost and decrease environmental pollution in manufacturing process, a sort of biodegradable castor oil-based emulsion is developed, whose physical and chemical properties can correspond with the national standards. The cooling and lubricating properties of the emulsion are better while machining steel materials through comparative experiments with certain imported commodity synthetic cutting fluid. The emulsion can successfully substitute for commodity fluid because of its high performance-price ratio.

Introduction

Main effects of cutting fluid in machining include cooling, lubricating, cleaning and rust protection. However, emission of conventional cutting fluid contaminates land and water, and destroys the environment. A variety of green machining technologies, such as dry machining [1,2], MQL (Minimum Quantity Lubrication) [2,3] and cold-air cutting [4,5], come into existence to reduce production costs and environmental pollution. However, the application of these technologies is limited because of the characteristics of the technology itself (such as dry cutting) or the need to re-construct old setup or purchase new equipments (such as the device for MQL and cold air).

It is a more appropriate way for the companies to considerably use traditional cooling equipments to achieve green machining. The ecological cutting fluid with natural biodegradation doesn't pollute the environment or require the purchase of equipments. Vegetable oil [6,7,8], such as rapeseed oil, cottonseed oil, rice bran oil, palm oil and castor oil, etc., commonly used as green cutting fluids, has good lubricating property, high viscosity index, non-toxic and better biodegradable ability.

The production of castor oil in China ranks second in the world, so it has a great advantage to develop castor oil-based lubricants [9]. Castor oil is mixture of a variety of fatty acid and triglycerides, and has become an important chemical raw materials and chemical intermediates for its molecules containing hydroxyl groups, double bonds, ester and other functional groups to participate in a variety of chemical reactions. At present, there are almost 170 kinds of derivatives and more than 2000 series of products based on castor oil raw materials in foreign countries [10]. In China there are only a few dozen of its derivatives, thus it is of great significance to further research and develop castor oil derivatives. In this study, a new green castor oil-based emulsion has been successfully developed. Comparing with certain imported commodity synthetic cutting fluid, the cutting quality of castor oil-based emulsion is prior to that.

Characteristic of Castor oil-based emulsion

Physical and chemical properties of castor oil. Castor oil is the unique vegetable oil containing hydroxy acid in nature (12-hydroxy-9-octadecenoic acid, molecular formula $C_{18}H_{34}O_3$, commonly known as ricinoleic acid). A large number of unsaturated ricinoleic acids of castor oil account for 85%~95% of the total fatty acids, which causes good biodegradability (Fig.1) and biodegradability of castor oil is up to 98%.

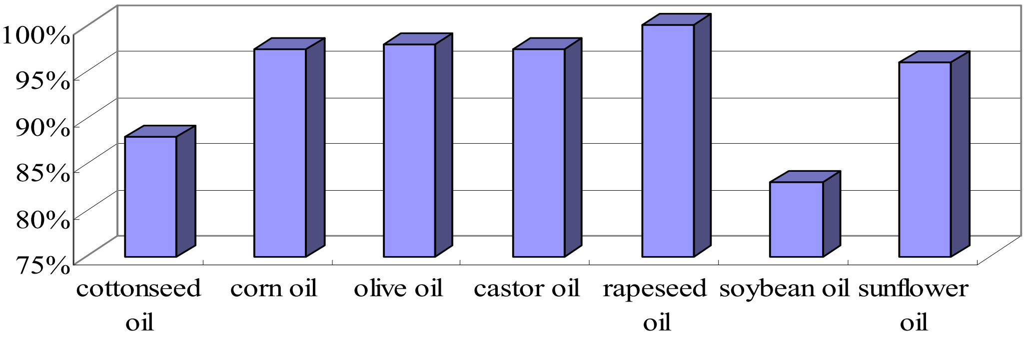


Fig.1 Biodegradability of several vegetable oil (ECEL-33-T-93) [11]

Ricinoleic acid has one double bond which can cause good low temperature performance and oxidation stability, and a hydroxyl which can chemically bond with the polar groups on metal surface and so there are good lubricating properties. As shown in Table 1, by the four-ball friction test, the maximum non-seizure load (PB) is 785N and is the highest for castor oil than for other vegetable oils; The ball wear scar diameter (WSD) is 0.58mm, slightly larger than the rapeseed oil and olive oil, far less than other vegetable oils.

Table 1 Composition and Lubricating properties of several vegetable oils [12]

Vegetable oil	Oil content(%)	Viscosity(40℃,mm^2/s)	PB（N）	WSD（mm）
Cottonseed oil	14~25	24	692	0.68
Corn oil	3~6	30	685	0.60
Olive oil	38~49	34	492	0.54
Castor oil	50~60	232	785	0.58
Rapeseed oil	35~40	35	628	0.53
Soybean oil	18~20	27.5	588	0.72
Sunflower oil	42~63	28	540	0.64

Emulsion additives. Extreme pressure and antiwear agents react to friction surface to form protection films and primarily reduce wear under boundary lubrication to prevent scratches and sintering a large area. Optional additives: T306 (cresyl phosphate ester) and T305 (sulfur phosphoric acid derivatives containing nitrogen), and other functional additives were added according to a certain ratio.

Emulsion properties. According to national standard GB6144 of cutting fluid, the physical and chemical tests of castor oil-based emulsion were carried out. The relevant parameters meet national standards (Table 2).

Experimental equipments and parameters

A ultra-precise turning center SB-CNC was used to turn workpiece. Cutting force was measured with Kistler three-component dynamometer (type 9257B) and Dewe800 data acquisition system. Surface quality was measured with roughness tester MITUTOYO SJ201. Precision turning normalized 45 steel and hard aluminum LY12 were performed using castor oil-based emulsion and commodity fluid respectively. Experimental conditions and parameters are shown in Table 3.

Table 2 Physical and chemical properties of castor oil-based emulsion

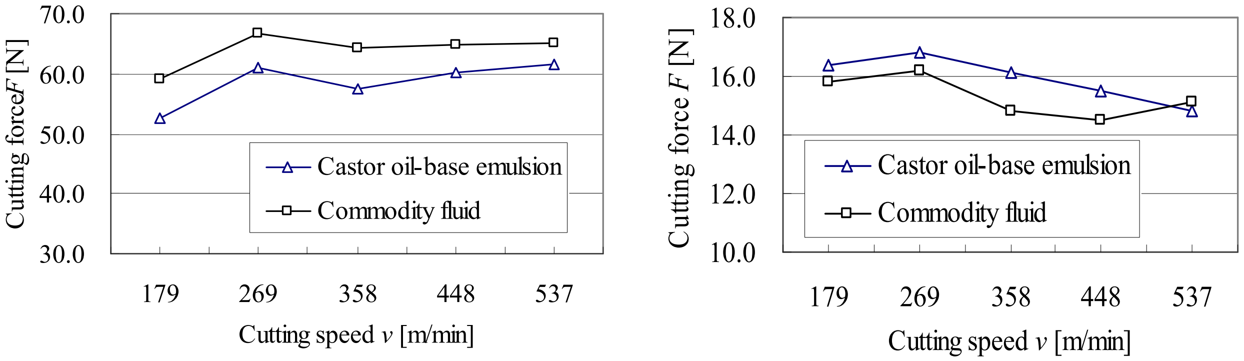
Items			Indicators
Dilution rate(5%)	Appearance		Transparent
	pH value		7.0~7.5
	stability（15~35℃,24h）,ml		0.5
	Defoaming property（distilled water）, ml/10min		≤2
	Derust property: first grade grey cast iron（35±2℃）	single（48h）	Qualified
		lamination（8h）	Qualified
	Corrosion test:90±2℃,24-hour immersion	LY12	First grade

Table 3 Experimental parameters

Tool model and angle	CoroTurn 107 turning tool（45steel）	α_o=0°，γ_o=7°，κ_r=75°，κ'_r=15°
	T-MAX U aluminum tool（LY12）	
Process parameters	Cutting speed *v*（m/min）	179，269，358，448，537
	Feed rate *f*（mm/r）	0.02，0.03，0.04，0.05，0.06
	Cutting depth a_p（mm）	0.3
Cutting fluids	Emulsion fluid	Flux 8.1L/min, volume concentration 5%
	Commodity fluid	

Results and discussions

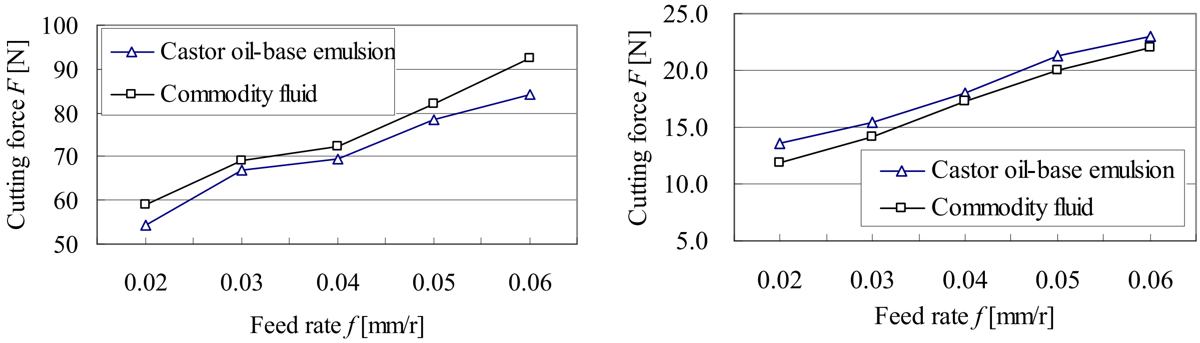
Influences on cutting force. Fig.2 shows the influences of cutting speed on cutting force when precisely turning 45 steel and LY12 (f=0.03mm/r, a_p =0.3mm). Cutting force of machining 45 steel is far higher than that of LY12, gradually increases with the increase of cutting speed at the beginning, reaches its maximum value at speed 269 m/min, and then shows a decreasing trend. The main reason is that BUE (build up edge) comes into being in the low-speed stage and cutting force is mainly affected by the formation and disappearance of BUE when cutting force is less than threshold limit value of about 269 m/min. When cutting speed is greater than the threshold limit value, the cutting heat and temperature increase , and the friction coefficient and chip deformation decrease as the cutting speed increases, which makes the cutting force gradually decreased.



a) 45 steel b) LY12

Fig.2 Influences of cutting speed on cutting force

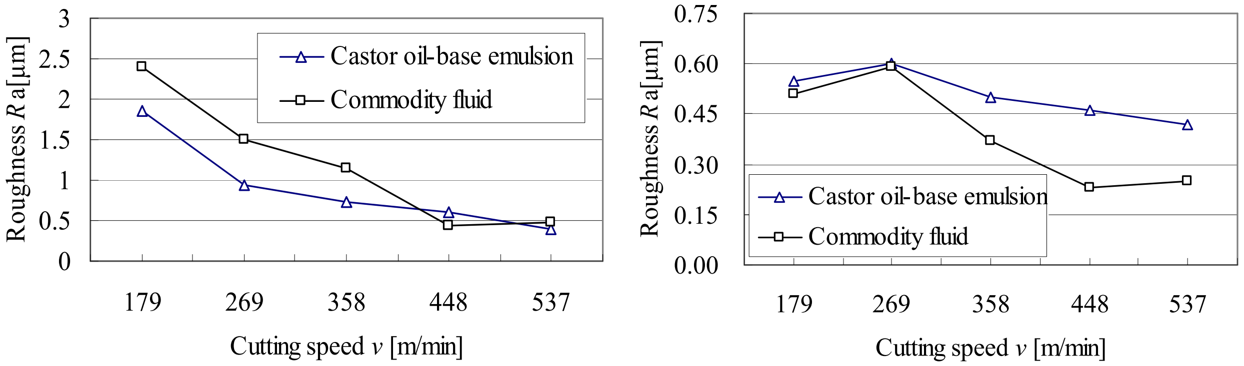
Fig.3 shows the influence of feed on the cutting force (v=358m/min, a_p=0.3mm). Cutting force of machining two materials increases and shows a linear growth with the increase of feed. The influence of feed on cutting force is obvious and great. Such as machining LY12, cutting force for commodity fluid increases from 11.8N to 22N when the feed rate increases from 0.02mm/r to 0.06mm/ r.



a) 45 steel b) LY12

Fig.3 Influences of feed rate on cutting force

Influences on surface roughness. Fig.4 shows the influences of cutting speed on surface roughness when precisely turning 45 steel and LY12. According to Fig.4, surface roughness gradually decreases as cutting speed increases. Chip deformation and the friction coefficient between the chip and rake face decrease as cutting speed increases, which certainly makes surface roughness decreased. Compared with 45 steel, LY12 is a very easy-cut material, relative machinability Kr> 3.0, which make it more likely to gets good surface quality. For this reason, the roughness of turning YL12 is much smaller than that of 45 steel. Roughness reaches the maximum value at 269m/min when machining LY12 because of the flutter of experimental system.

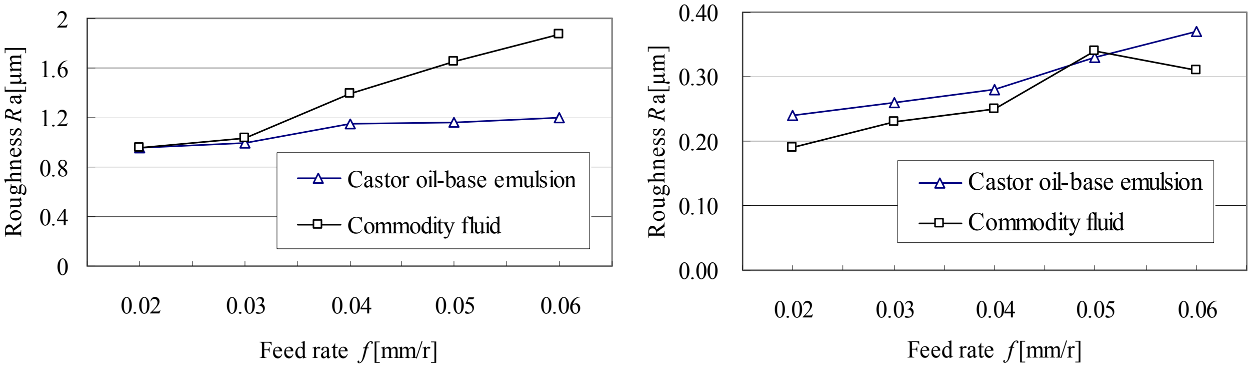


a) 45 steel b) LY12

Fig.4 Influences of cutting speed on roughness

Fig.5 shows the influences of feed rate on surface roughness when precisely turning 45 steel and LY12. According to Fig.5, surface roughness shows an increasing trend. Surface roughness doesn't obviously increase at the beginning, because the feed rate and residual height of the workpiece are small. The influences of cutting force, cutting depth, cutting vibration, and other factors on roughness increase as the feed rate and at the same time residual height increase also. For this reason, surface roughness shows a significantly faster increase when feed is more than 0.03mm/r.

The experiment shows machining quality for 45 steel is superior to that for LY12 with castor oil-based emulsion because of phosphate-based and sulfur-based extreme pressure additives. Under normal conditions, extreme pressure additives form a physical adsorption film on workpiece surface. Under larger load conditions, organic phosphorus anti-wear extreme pressure agent can hydrolyze or be thermally decomposed into phosphoric acid (or phosphite, etc.) which reacts to iron in 45 steel to form organic or inorganic phosphate film (or sub-phosphate, etc.); organic sulfur compounds react to iron and form thiol-iron film which plays a role in anti-wear. When working condition changes into extreme pressure state, due to C-S bond rupture, inorganic iron sulfide protective film comes into being and protective effect of film can continue to more than 800℃, which makes protective film bear large loads [13]. So cutting force can be reduced and surface roughness be lowered when machining 45 steel than LY12.



a) 45 steel b) LY12

Fig.5 Influences of feed on surface roughness

Conclusions

A new type of castor oil-based emulsion is successfully developed and application scope of castor oil derivatives is broadened. Machining quality of castor oil-based emulsion is prior to certain merchant fluid and can substitute imported products. Polar additives, cresyl phosphate esters and sulfur-phosphoric acid derivatives containing nitrogen, are more suitable for machining 45 steel than LY12.

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