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Recycling of Used Lubricant by Utilizing High Electric Field

Panida Prawitwong, Yukihiro Ishikuri, Eiko Akaishi, Eichi Tajiri, Takashi Suzuki* and Shoji Takigami**

Shinko Giken Co., Ltd, 124-2, Okubo-cho, Ota, Gunma 379-2306
Fax: 81-277-79-0766, e-mail: info@shinkogiken.jp
*Gunma Prefectural Industrial Technology Center, 884-1, Kamesato, Maebashi, Gunma 379-2147
Fax: 81-272-90-3040, e-mail: suzuki@tec-lab.pref.gunma.jp
**Gunma University, 1-5-1, Tenjin-cho, Kiryu, Gunma 376-8515
Fax: 81-277-30-1141, e-mail: takigami@chem-bio.gunma-u.ac.jp

Used lubricant for precision mechanical machining includes a considerable amount of very fine metal particles. Incorporation of the fine particles is a factor of the deterioration of the lubricant. If it were possible to remove the particles effectively, the used oil could be reused. Many attempts have been done to remove the metal particles using several methods, i.e., sedimentation, filtration and centrifugation. Since the viscosity of the used oil is quite high, those methods are not suitable to separate metal particles thoroughly. We found that the metal particles migrated under the high electric field and aggregated on the electrode. After the treatment by the high electric field, the transmittance value recovered to about 75% of that of the original oil. The kinematic viscosity of the treated oil was almost the same as that of the virgin oil. The chemical structure of the cutting oil and additives were hardly degraded by the regular use of the lubricant and the treatment of high electric field. The application of the high electric field is a useful method to remove the metal particles effectively.
Key words: lubricant, cutting oil, recycle, metal particle, high electric field

1. INTRODUCTION

Lubricant has been introduced into the metal cutting and the precision process for the purpose of cooling and lubricating the contact surface between the tool and the work pieces. The use of lubricants produces a homogenous product, increases the tool life, contributes to a more economical cutting speed and generally improves the efficiency of the production systems. The main components of cutting oil are petroleum hydrocarbon and additives. Typical additives used are extreme pressure additives (usually phosphorous, chlorine or sulfur products) which act to reduce friction despite the formation of low strength surface layer. Other additives include detergent, anti-misting and corrosion inhibitors [1]. After using, the lubricant is contaminated with a considerable amount of very fine metal particles. Incorporation of the fine particles is a factor of the deterioration of the lubricant. If it were possible to remove the particles effectively, the used oil could be reused. Many attempts have been done to remove the metal particles using several methods such as sedimentation, filtration and centrifugation [2]. Since the viscosity of the used oil is quite high, those methods are not suitable to separate the metal particles thoroughly. We found that the metal particles migrate under the high electric field and aggregate on the electrode. Using this method, the metal particles could be separated from the used lubricant and the lubricant is possible to reuse.

Here, the used lubricant was regenerated under the condition of the high electric field. The chemical and physical properties of the regenerated oil were investigated and the possibility of recycling method was discussed.

2. EXPERIMENTAL

2.1 Material

The lubricant used in this study was non-chlorine, anti-mist cutting oil. The cutting oil contains petroleum hydrocarbon as a main component and sulfur compound as an extreme pressure additive. The exact formulation of the oil was not indicated by the manufacturer. Used lubricant was the cutting oil that had been used in the cutting process of stainless steel and aluminum works.

2.2 Centrifugation method

The used cutting oil was centrifuged at 10,000 g for 30 minutes at 25 °C to remove the metal particles. The effect of centrifugation on recycling process was investigated.

2.3 High electric field lubricant recycling system

Schematic diagram of lubricant recycling system is shown in Fig. 1. Two types of electrodes, high voltage electrodes and accumulated electrodes, were set in the reactor tank filled with the used lubricant. The high voltage electrodes were connected with a high voltage power supply (5-10 kV) and generated high electric field along the reactor tank. The accumulated electrodes were grounded. Using high voltage, the metal particles in the used lubricant migrated under the high electric field and aggregated on the accumulated electrodes, and then the regenerated lubricant was collected. The treatment time was varied from 0 to 60 hours.

2.4 Spectrometry

Fourier transform infra red (FT-IR) measurements of the lubricants were carried out using a Magna 560 FT-IR spectrometer equipped with a Continuμm infrared microscope (Nicolet). Transmission and absorption spectra of lubricants were obtained using a U-3000 spectrophotometer (Hitachi).

2.5 Viscosity measurement

The viscosity of lubricants was measured using a SV10 vibration type viscometer (A&D). The samples were heated to ca. 90 °C and the viscosity measurement was performed at cooling process. In this method, the viscosity is determined as the dynamic viscosity. The dynamic viscosity was converted to the kinematics viscosity using the specific density.

3. RESULTS AND DISCUSSION

The virgin lubricant is clear oil with light yellowish brown. After using, the lubricant was contaminated with a considerable amount of very fine metal particles. The oil changed to dark color with less transparency. The particles should be removed before reuse. The conventional method for removing the metal particles is the centrifugation method. Fig. 2 shows the effect of centrifugation on regenerating of the used cutting oil. After the centrifugation at 10,000 g for 30 minutes, the contaminant was separated from the oil. The used oil became clear and the black sediment is considered to be the metal particles contaminated from the cutting process. The virgin oil also had a small amount of sediment after the centrifugation. Chemical compounds containing sulfur, chlorine or phosphorous are used as oil additives for the purpose to improve the functionality of cutting oil [1]. Iijima et. al. reported that approximate 95% of metal chips and degraded materials were removed from the waste metal cutting oil after the centrifugation at 800 and 4000 g. The recovered oil showed a slight difference in the sulfur and the chlorine contents compared with those of the virgin oil [4].

To investigate the chemical composition of the sediments in the virgin oil, the elemental analysis was carried out using an electron probe micro analyzer (EPMA). The sediment contains carbon, oxygen, calcium and a small amount of sulfur. Accordingly, the sediment of the present virgin oil is due to the extreme pressure additive. The oil additives are also removed together with metal particles in the case of the present used oil. Therefore, the centrifugation method is not proper for the recycling of cutting oil.

Using high voltage, the effect of treatment time on the appearance of regenerated oil is shown in Fig. 3. The color of treated oil changed from dark to light brown with increase of the treatment time and showed yellowish brown at 60 hours of treatment. The transparency of treated oil increased with increase of the treatment time.

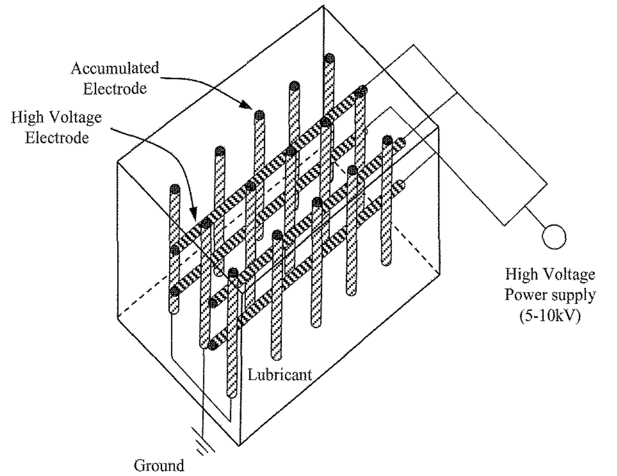

Fig. 1 Schematic diagram of lubricant recycling system [1].

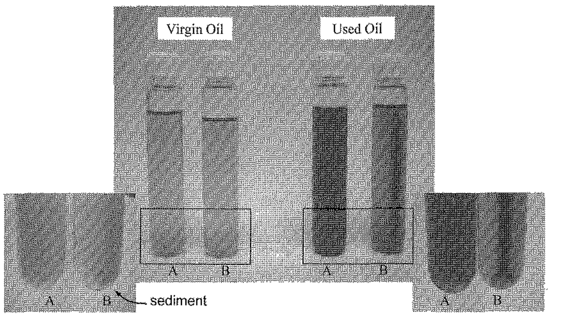

Fig. 2 Effect of centrifugation on regenerating of used oil; A: before centrifugation, **B**: after centrifugation (conditions: 10,000 g, at 25 °C for 30 min.).

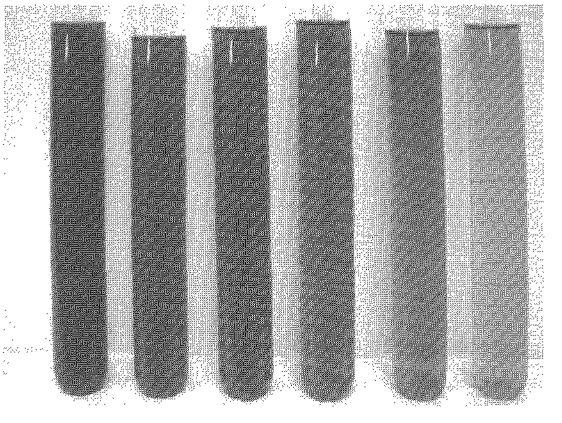

Fig. 3 Effect of treatment time on appearance of regenerated oil. From left to right: used oil, 3 h, 6 h, 40 h, 60 h treated oil and virgin oil.

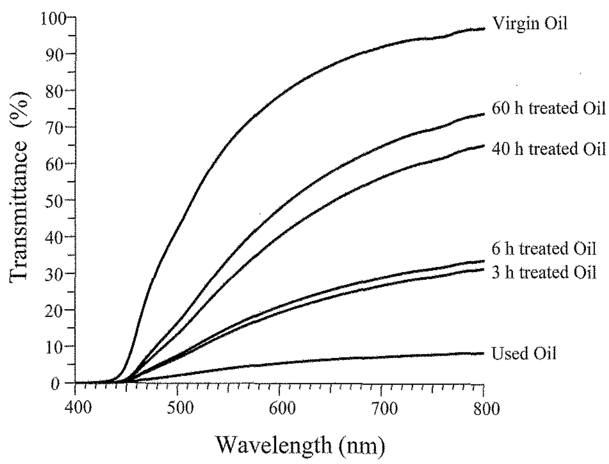

Fig. 4 Effect of treatment time on transmittance of regenerated oil.

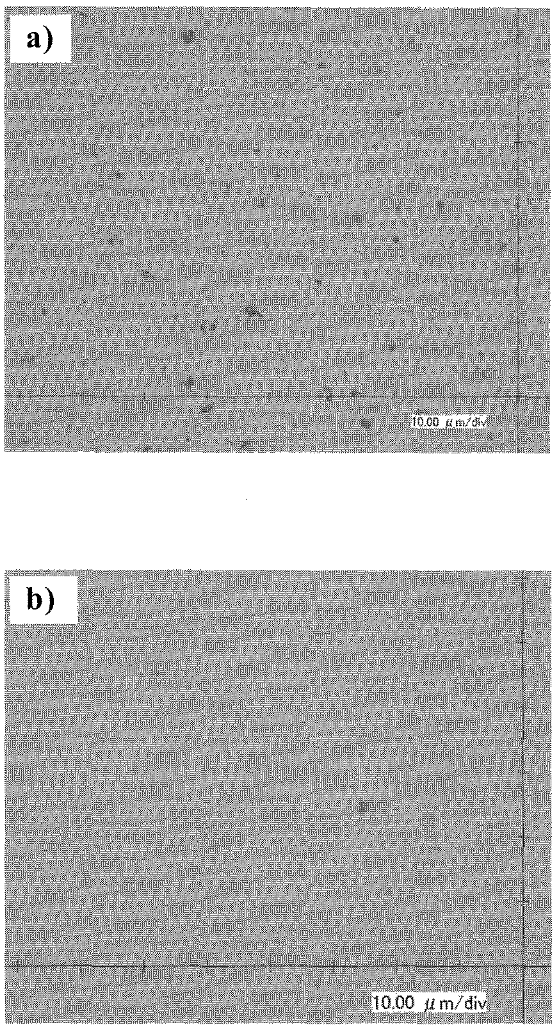

Fig. 5 Photomicrographs of a) the used cutting oil and b) the regenerated oil treated under the high electric field for 60 hours.

The transmittance of the cutting oils treated with high electric field for various time was measured using the spectrophotometer. The transmission spectra of the virgin oil and the treated oil are shown in Fig. 4. The transmittance of the virgin oil increased with increase of the wavelength and reached 100% at 800 nm. The transmittance value of the used cutting oil was lower than 10 % for the wavelength range of 400 to 800 nm. The transmittance of the treated cutting oil increased with increasing the treatment time and the oil treated for 60 hours showed ca. 75 % of transmittance at 800 nm.

Photomicrographs of the used cutting oil and the oil treated under the high electric field for 60 hours are shown in Figs. 5 a) and 5 b), respectively. Numerous metal particles were observed in the used cutting oil. The average particle size is smaller than 5 micrometer. Though quite small amount of metal particles could be observed in the treated oil, application of the high electric field is the useful method to remove the metal particles effectively.

To investigate the state of additives, various cutting oils were diluted in n-hexane and UV measurements were performed using n-hexane as a reference. The UV spectra of the samples are shown in Fig. 6. The virgin cutting oil showed three absorption bands around 220, 265 and 300 nm. Although the intensity of the absorptions was slightly lower than that for the virgin oil, the similar patterns of spectra were observed for the used oil and the treated oil. This confirms that the additives hardly degrade by the regular use of the lubricant and by the treatment of high electric field.

The chemical change of the cutting oil was studied using the FT-IR method. Fig. 7 shows the FT-IR spectra of the various cutting oils. The virgin oil showed extremely strong absorptions due to the methylene anti-symmetry stretching vibration at 2925 cm^{-1}, and the methylene stretching vibration at 2854 cm^{-1}. The stretching vibration peak due to ester carbonyl groups appeared at 1746 cm^{-1}. Two bands observed at 1461 and 1377 cm^{-1} were due to the scissoring vibration and the waggling vibration of methylene groups [5]. A weak absorption due to the rocking vibration of methylene groups also observed at 721 cm^{-1} [6]. The used oil showed the same pattern. In the case of the treated oil, the treatment time was changed from 3 to 60 hours, the spectra of all treated oils showed almost similar patterns to that for the virgin oil. It is deduced that the core chemical structure of cutting oil is not significantly changed and no new chemical groups are introduced by utilizing high electric field.

Fig. 8 showed the relationships between the viscosity of cutting oil and temperature. The viscosity of the virgin cutting oil increased with decreasing temperature. Similar trends were observed for the used oil and the treated oil. The dynamic viscosity of cutting oil was determined at 40 °C and the value was converted to the kinematic viscosity. Both values are listed in Table I. The kinematic viscosities of the virgin cutting oil and the treated oil were 21.07 and 20.97 $mm^2 \cdot s^{-1}$, respectively. Though the viscosity of the centrifuged used oil was slightly higher, significant differences were hardly observed among the three samples.

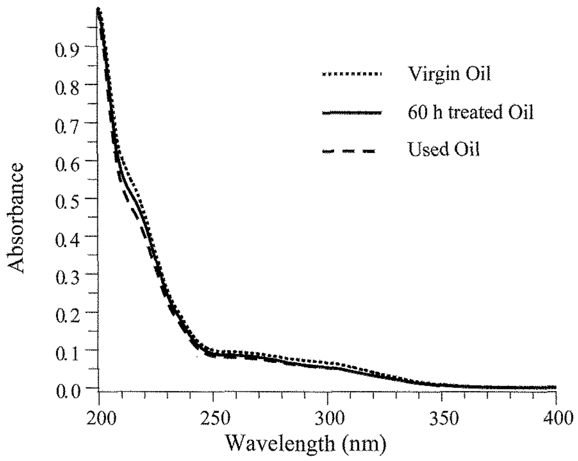

Fig. 6 UV absorpsion spectra of cutting oil.

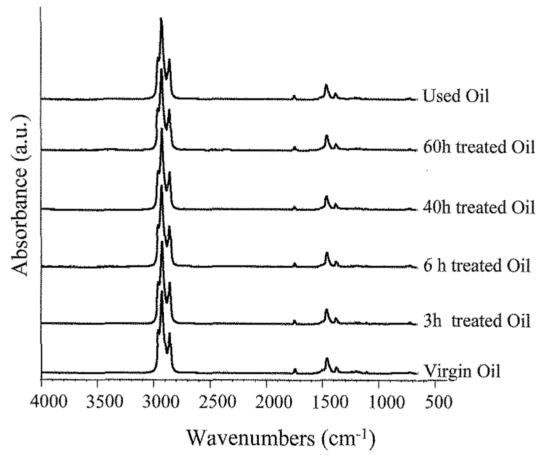

Fig. 7 FT-IR spectra of regenerated Oil.

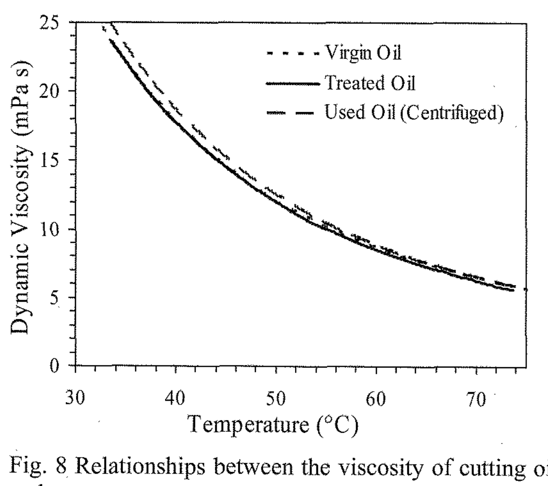

Fig. 8 Relationships between the viscosity of cutting oil and temperature.

Table I Viscosity of cutting oil at 40 °C.

Sample	Dynamic viscosity (mPa·s)	Kinematic viscosity ($mm^2 \cdot s^{-1}$)
Virgin oil	19.31	21.07
Treated oil	19.22	20.97
Used oil (centrifuged at 35,000g for 30 min.)	20.34	22.20

4. CONCLUSION

The used cutting oil contains the considerable amount of fine metal particles. The centrifugation method is not proper for the recycling of cutting oil because of removement of the oil additives together with metal particles. Using the high electric field, fine metal particles can be separated from the used oil. After the treatment of 60 hours, the transmittance value recovered to about 75% of that of the original oil and the kinematic viscosity of the treated oil was almost the same as that of the virgin oil. The core chemical structure of the cutting oil and additives were hardly degraded by the regular use of the lubricant and by the treatment of high electric field. It was found that the application of the high electric field is a useful method to remove the metal particles effectively.

5. REFERENCES

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