Study of tribological properties of vegetable oil added with graphite as additives for lubricants

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Abstract*– Conventional liquid lubricants are constituted of a base oils and (nano)additives presenting specific properties, such as friction reduction and antiwear performances. Mineral or synthetic base oils are used due to their stability and especially their competitive prices. Vegetable oils (VO) owing the increasing interest of the environmental impact constitute a suitable alternative for lubrication. Two different VO are studied. In a first part, the comparative effect of the addition of VO as additive on the tribological performances of dodecane, the oil-based is investigated. Previous studies have shown that the friction properties of graphite particles in the presence of dodecane drecrease. We evaluate the influence of VO as additive on the properties of graphite/VO1/dodecane and graphite/VO2/dodecane lubricant mixtures. Raman spectroscopy and scanning electron microscopy performed to analyze the tribofilms after friction confirmed the collective liquid/particles effects inside the contact during sliding.
Keywords—vegetable oil, graphite, mixed lubrication

I. Introduction

Green lubrication presents an increasing interest in world industrial and economic development. Lubricant generally with the majority being petroleum-based are the subject of numerous studies due to the progressive depletion of the world reserves of fossil fuels but also owing to concerns on their environmental impact. In the case of liquid lubricant, a good combination between oil base and additives is the key to improve the lubrication process.

The amphiphilic properties that result from the fatty acid composition of vegetable oils (VO) constitute to better lubricity and effectiveness as anti-wear compounds than mineral or synthetic lubricant oils. The attraction of natural oils is due to the structure of the triacyglycerol which contains long chains of polar fatty acids that are desirable in boundary lubrications because they adhere to metallic surfaces remain closely packed and create a thin monolayer that is effective reducing friction and wear. Despite the environmental advantages, pure VO does suffer from poor thermal and oxidative stability, biological deterioration, hydrolyctic instability, poor fluid flow behavior, solidification at low temperatures and high wear rates [1,2]. Green solid lubricants are a new class of "powder lubricants" consisting to lamellar crystal structures with low interlayer friction. Graphite is the conventional lamellar powder lubricant. Their crystal structure, in which atoms lying on the same layer are closely packed and strongly bonded together by covalent bonds and the layers are relatively far apart due to the weak Van der Waals force. Lamellar powder lubricants accomplish this by aligning their layers parallel to the direction of motion and sliding over one another to minimize friction. Moreover, these powder lubricants can lubricate in extreme conditions such as high or low temperatures and pressures [3,4].

The purpose of this study was to investigate how the weight percentage of vegetable oil add influence the tribological properties of dodecane. Two different vegetable oils; VO1 and VO2 were studied between 0.5w% and 2w%. In a second part, the addition of graphite was evaluated. The tribofilms obtained after friction tests of graphite/w%VO1/dodecance and graphite/w%VO2/dodecane lubricant mixtures were analyzed with Raman spectroscopy and scanning electron microscopy.

II. Methodology

Dodecane, ReagentPlus 99% used in this study provided by Sigma-Aldrich and considered to be the oil-base. Vegetable oils were extracted from local precursors and provided by Phytobokaz Laboratory. The tribological properties of different mixtures of the two types of vegetable oils (VO1 and VO2) have been carried with 0.5, 1, 1.5 and 2w% in dodecane. Particles of graphite were then added at 1w% for mixture of 1 and 2w% of VO in dodecane.

The tribological properties of solid particles were evaluated using an alternative ball-on-plane tribometer consisting of an AISI 52100 steel ball rubbing against an AISI 52100 steel plane on which the tested material was deposited. A normal load F_N of 10 N was applied leading to a contact diameter of 140 µm (according to Hertz's theory) and a maximum contact pressure of 1 GPa. The sliding speed was 4 $mm.s^{-1}$.

Scanning Electron Microscopy (SEM) using secondary electron imaging characterized the particles and their corresponding tribofilms. At the end of the friction tests, planes with tribofilms were introduced in a Hitachi H600 scanning electron microscope running at 20 kV with a LaB6 cathode. Condenser illumination and objective aperture are adjusted to raise a point-to-point resolution <20 nm.

Raman spectroscopy studies were performed with a HR 800 Horiba multi-channel spectrometer using a Peltier-cooled CCD detector for signal recording. The exciting line was 532 nm wavelength line (Nd YAG laser).

III. Results and Discussion

Figure 1 shows band intensities in infrared spectra of pure vegetable oils, VO1 and VO2 taken under ambient conditions. The most conspicuous changes are at wavenumbers 1096 and 1711 cm^{-1}. Bands assignments according to literature are C=O bond of esters and amide bonds, respectively [5]. The viscosity of pure vegetable oils is 72 mPa.s for VO1 and 95 mPa.s for VO2. The friction coefficient of pure VO is different but they have excellent tribological properties compare to pure dodecane (≈0.35), the base oil used; $\nu_{pure\ VO1} \approx 0.085$ and $\nu_{pure\ VO2} \approx 0.090$. The presences of vegetable oil as additive at weak percentage decrease the friction coefficient of dodecane. The mixtures present optimized tribological performances with approximately 1.5w% of VO (Figure 2). In the both VO, the friction coefficients stabilize at the same value and the contacts diameter measured on the ball after 2000 cycles correspond to Hertz theory value.

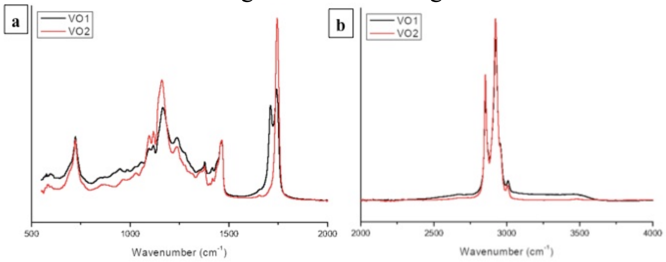

Fig. 3: Infrared spectra of pure VO1 and VO2 at 500 to 2000 cm-1 **(a)** and 2000 to 400 cm-1 **(b)**

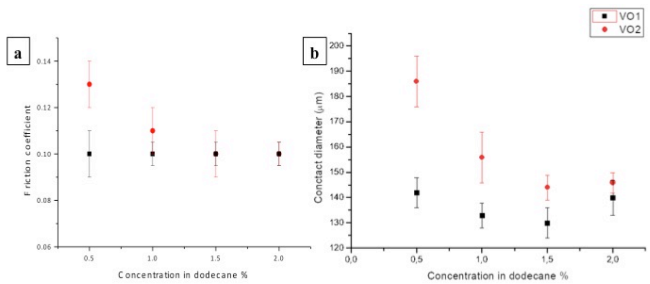

Fig. 2: Evolution of the friction coefficient values **(a)** and the contact diameter measured after 2000 cycles **(b)** of mixture with different weight percentage of VO added in dodecane.

With graphite particles, the friction behaviors are different according to the percentage of VO added in dodecane (Figure 3). In previous studies, we have shown that the friction coefficient of graphite/dodecane is 0.06 and due to the simultaneous presence of weak viscosity liquid and particles in the sliding contact [4,5]. According to this, we show no influence of the friction coefficient of graphite is observed in the presence of pure VO ($\nu_{graphite + pure\ VO} \approx 0.090$). Differences are obtained at the addition of VO in graphite/dodecane. Indeed, in both cases, VO1 and VO2, the friction is higher with 1w% of VO than 2w%. However, we observed excellent influence of the presence of 2w% of VO2 on the friction coefficient of graphite. Viscosity parameter is not sufficient to explain the friction reduction process.

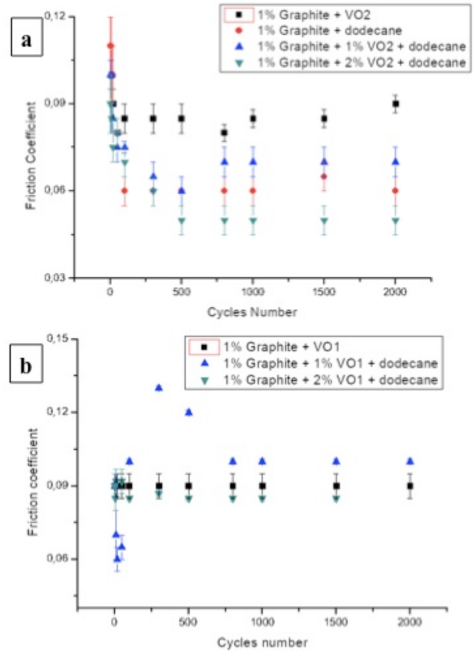

Fig. 3: Evolution of the friction coefficient values of the mixtures with graphite particles at 0, 1 and 2w% of VO2 **(a)** and VO1 **(b)** in dodecane.

IV. CONCLUSION

The presence of liquid in the sliding contact improves the friction coefficient of graphite particles. This reduction is due to the presence of both liquid and particles in the sliding contact. We have shown that the presence of a vegetable oil as additive at weak percentage decrease the friction coefficient of dodecane, the base oil of the study. For the both vegetable oil, VO1 and VO2, the stable friction coefficient values in dodecane are identic. The influence of the type of VO is observed at the addition of graphite particles. Excellent results are obtained with graphite/VO2/dodecane compare to graphite/VO2/dodecane lubricant mixtures at 2w%.

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Digital Object Identifier: (to be inserted by LACCEI).
ISSN, ISBN: (to be inserted by LACCEI).