

INVESTIGATION OF THE TEMPERATURE EFFECT ON THE STEEL BALL WEAR LUBRICATED WITH ALIPHATIC ALCOHOLS AND THEIR TRIBOCHEMISTRY

Mohamed Al-Nozili

Chemistry Department, Faculty of Science, Ibb University, Yemen

Mufid Obadi

University of Hodeida, Faculty of Education, Department of Chemistry, Yemen

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ABSTRACT – *In the present work influence of operating temperature on wear of the steel ball sliding on steel disk, lubricated with individual alcohols 1-decanol C₁₀, 1-dodecanol C₁₂ and equimolar mixtures of these alcohols was investigated. Minimum wear values for individual alcohols were found at the temperature of 80 °C however, at 40 °C for binary mixtures of these alcohols. FTIR surface analysis after friction process presents 1-decanol new absorption bands mostly in the region of 1522 – 1549 cm⁻¹ which usually is combined with the absorption bands around 1653 – 1680 cm⁻¹ were found in deposits formed on the steel substrates. They have been assigned to organometallic compounds including double bonding.*

KEY-WORDS: *Alcohols, anions, radical anions, boundary lubrication, tribochemistry, NIRAM, FTIR, electron emission.*

1. INTRODUCTION

Oxygen containing compounds such as fatty acids and alcohols are superior friction reducing agent. These compounds adsorb or react on rubbing surfaces to reduce adhesion between contacting asperities and limit friction, wear and seizure [1,2]. However, not all is known about the action mechanism and the reactivity of these compounds in sliding contacts of steel – steel surfaces.

Fatty alcohols and alkanediols are good examples of boundary lubricants for aluminum [3,4], Hironaka and Sakurai [5], pointed out that pentaerythritol partial ester which contains both hydroxyl and ester group is more effective as compared to the full ester. Tribochemical reactions of these additives with aluminum are very interesting, these particularly from the viewpoint of organometallic products resulting from alcohols. Another work [6] demonstrates that 3-allyloxy-1,2- propandiol is effective additive in reducing steel wear under boundary lubrication. Stinton et al [7] reported that alcohol groups favour the production of an adherent coating on sliding steel surfaces composed of many components, including alkynes dialkynes, alkenes, and dialkenes.

Reflection experiments on thin films of alcohols deposited on metal surfaces showed that the first molecular layer is generally oriented with the hydrocarbon chains normal to the surface. The monolayer of alcohols loses its orientation at a temperature close to the bulk melting point of the alcohol, and the disorientation temperature does not depend appreciably on the nature of the metallic substrate.

The practical and theoretical studies of lubrication with lubricants containing fatty alcohols have been conducted for decades. However not all is known about the action mechanism of these compounds in sliding contacts of steel – steel surfaces, Kajdas [8] put forward a viewpoint of anionic – radical concept which explains the lubrication mechanism of alcohols considerably. Not much is known about the reactivity of alcohols towards steel during sliding. For example the influence of straight chain length of alcohols $C_4 - C_{14}$ on the wear of steel – on – steel tribological elements have been investigated [9]. It was found that the wear decreases with increase chain length of alcohols. Another work [10] proposed that the tribological interaction of alcohols may be due to the formation of alcoholates as proposed by Kajdas and oxidation to carboxylic acids as proposed by Dauchot.

Research described in the present work relates to tribochemistry of alcohols C_{10} and influence of temperature on the wear ball steel against steel under the lubrication of individual alcohols C_{10} , C_{12} and equimolar mixtures of these alcohols $C_{10} + C_{12}$. Also it aims to providing more informations on mechanisms of wear of the steel rubbed against steel and lubricated with these compounds. Thus, the primary objectives of this paper are: (i) to determine the influence of temperature on the steel matting element wear in absence of individual alcohols and binary systems of selected alcohols, and (ii) to elucidate tribochemical reactions of C_{10} alcohols proceeding on the steel mating elements.

2. EXPERIMENTAL TECHNIQUE

2.1. Apparatus And Lubricants

The wear tests were performed using the steel ball-on steel disc tribological system. The applied tribometer was TESTER T-11 made in ITE Radom, Poland [11]. The tribometer makes possible to rise and control the temperature inside test chamber. The used balls were made from bearing steel LH 15 (AISI 52100). The discs were machined from the same steel. Detailed descriptions of specimens are included in **Table 1**. The specimens were clamped in place with stainless steel holders. The lower holders contained the lubricant fully flooding the contact region. A dead – weight-loading system applied the normal force. Pure alcohols C_{10} , C_{12} and equimolar mixtures of these alcohols were selected as lubricants for the wear test.

2.2. Test Conditions And The Procedure

All experiments were carried out under the following conditions: load 9.81N, sliding velocity 0.25 m/s, sliding distance 500m, operating temperature 20, 40, 60, 80 and 100°C. The test conditions were designed to result in boundary lubrication at the sliding interface. Prior to use, the steel specimens were ultrasonically cleaned in acetone for 20 minutes. Three tests were performed for each alcohol tested. The seals were cleaned before testing the next alcohol. The ball wear scar diameter was measured after unloading the specimens, using a photomicroscope.

Table 1: Experimental set – up and test conditions.

Material system	Steel-on-Steel
Geometry	Ball-on-Flat
Specimens: Ball	3,18 mm diameter 63 HRC bearing steel $R_a = 0.3-0.35 \mu\text{m}$
Disc	25,4 mm diameter; 75 HRC bearing steel; 7 mm thickness $R_a = 0.5-0.55 \mu\text{m}$
Applied load	9.81N
Wear track radius	8 mm
Sliding velocity	0.250 m/s
Sliding distance	500 m
Temperature	20, 40, 60, 80, 100 °C

2.3. Surface Analysis

Products of chemical reactions present on the steel surface due to friction were identified by means of FTIR microscopy. The used instrument was Perkin-Elmer i-Series Microspectrophotometer. Reflection FTIR spectra were recorded by scanning in selected regions. The spectrometer was operated in mid-infrared frequency range ($4000-580 \text{ cm}^{-1}$) at the resolution of 4 cm^{-1} and signal-averaged over 100 scans for background and disc. Perkin-Elmer software IMAGE application allowed to generate spectra at any point of scanned surface. All obtained spectra were corrected by zapping of spurious bands, originated from carbon dioxide and water vapour, smoothing of each spectrum by Savitsky-Golay method and multipoint normalizing of base line using Perkin-Elmer software GRAMS 2000.

3. RESULTS AND DISCUSSION

The ball wear scar diameter lubricated with pure alcohols C_{10} , C_{12} and mixture of binary alcohols $C_{10} + C_{12}$ at different temperatures are summarized in **Table 2** and depicted in figures 1 and 2.

Figure 1 shows the ball wear scar diameter lubricated with pure alcohols C_{10} , C_{12} as a function of a temperature. This figure clearly shows that the ball scar diameter decreases with increasing the temperature up to $80 \text{ }^\circ\text{C}$, at which increases dramatically. On the basis of these data, it can be seen that, the tribochemical reactions of alcohols in boundary lubrication depend on a temperature. This may be related to hydrogen bonds,

which existence between the molecules of alcohols. Rising the temperature to 80 °C, causes rupture of hydrogen bonding forming free molecules of alcohols, which can create antiwear protective layers on the rubbing surface according to the mechanism NIRAM [12]. These antiwear protective layers distract from surface, at temperature more than 100 °C. This is may be responsible increase the wear at 80 °C.

Table 2: Comparison between the steel ball wear scar diameter lubricated by individual alcohols C₁₀, C₁₂ and the steel ball wear scar diameter lubricated by mixture of binary alcohols (C₁₀ + C₁₂) at different temperatures.

Alcohol name	WSD. mm*10 ⁻¹				
	T= 25 °C	T= 40 °C	T= 60 °C	T= 80 °C	T= 100 °C
1-dekanol	2.82	2.69	2.67	2.56	3.97
1-dodekanol	2.56	2.51	2.46	2.32	3.02
1-dodekanol + 1-dekanol	2.38	2.12	2.27	2.45	2.71

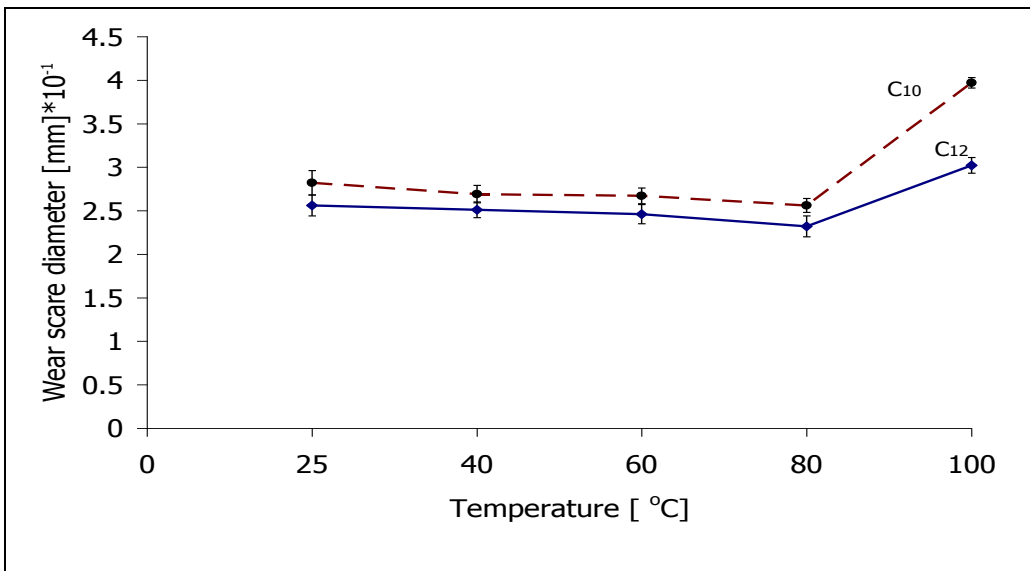


Fig. 1: Relationship between the steel ball wear scar diameter lubricated by individual alcohols 1-decanol (C₁₀), 1-dodecanol (C₁₂) and temperature.

Figure 2 represents the ball wear scar diameter lubricated by mixture of binary alcohols C₁₀ + C₁₂ as a function of temperature. Two major issues concerning these results are to be noticed:

- (i) the minimum wear was achieved at temperature 40 °C, and rise of temperature above 40 °C leads to increase the wear scar.

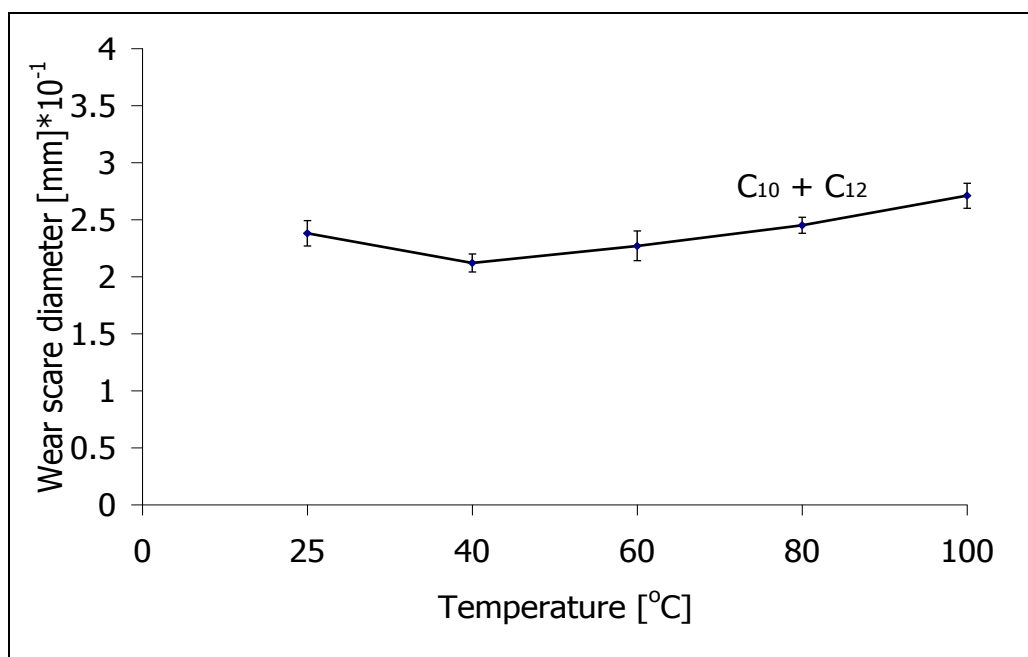


Fig. 2: Relationship between the steel ball wear scar diameter lubricated by binary mixture alcohols ($C_{10} + C_{12}$) and temperature.

(ii) The mixture of binary alcohols $C_{10} + C_{12}$ is very effective to reduce ball wear compared with individually alcohol C_{10} or C_{12} , (**Fig. 3**). Effectiveness of binary alcohols $C_{10} + C_{12}$ antiwear can be explained by the fact that, the antiwear protective layers which can creating on steel surfaces in presence of both alcohols C_{10} , C_{12} is due to following interaction:

Alcohol C_{10} --- steel surface, alcohol C_{12} --- steel surface and alcohol C_{10} --- alcohol C_{12} , however, the antiwear protective layers creating on steel surface by individually alcohols C_{10} , C_{12} is due to one interaction alcohol C_{10} – steel surface or alcohol C_{12} – steel surface. In this fact it can be concluded that, the antiwear protective layers creating on steel surface by mixture of binary alcohols C_{10} , C_{12} is most likely possible.

4-1 Tribochemical reactions of alcohols with steel surface

To explain tribochemical reaction mechanism of aliphatic alcohols in boundary lubrication conditions, FTIR surface analysis after the friction process was used. The preliminary FTIR spectrum taken from the steel wear track lubricated with 1-decanol presents in **Fig. 4**. Characteristic feature of this spectrum (**Fig. 4**) is an appearance strong absorption bands at 1522 cm^{-1} , 1549 cm^{-1} these peaks can be assigned to -C-O-group stretching in chelate compounds, and 1653 cm^{-1} , 1680 cm^{-1} assigned for compounds with double bonding [13].

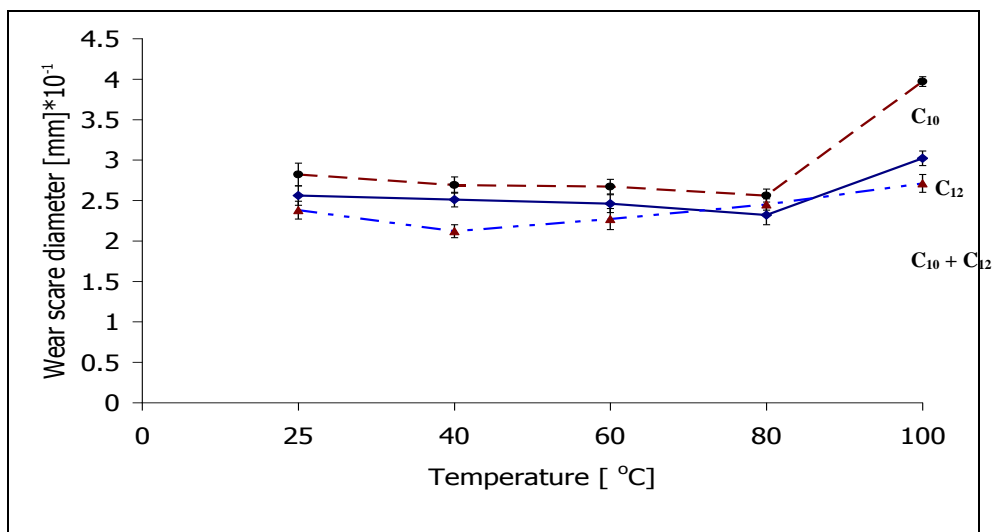


Fig. 3: Comparison between steel ball wear lubricated by individual alcohols C₁₀, C₁₂ and steel ball wear lubricated by mixture of binary alcohols (C₁₀ + C₁₂) at different temperatures.

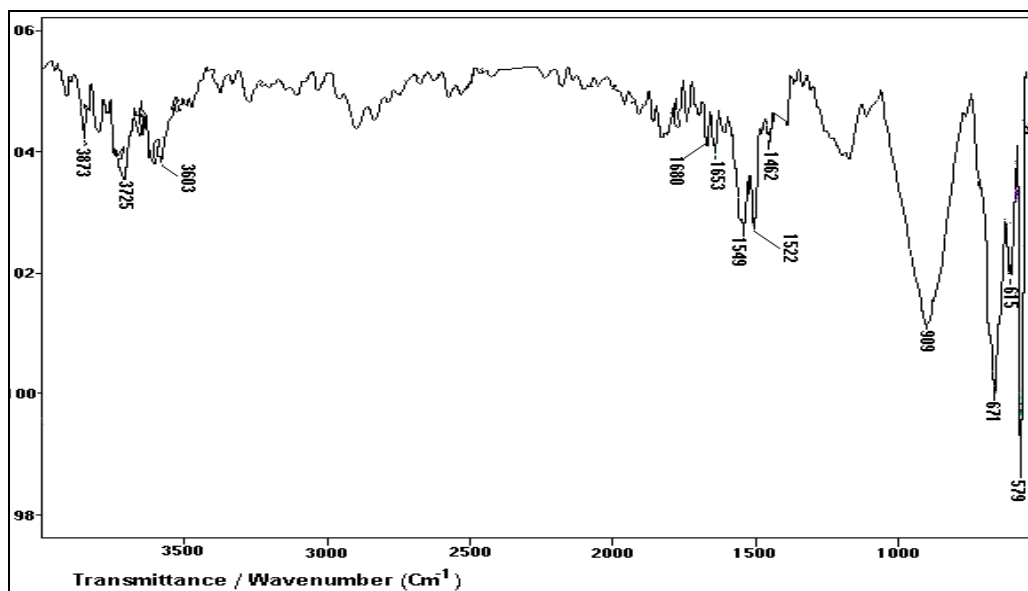
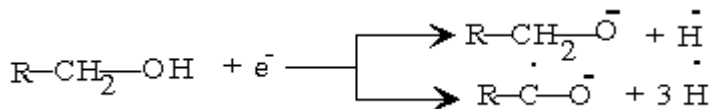


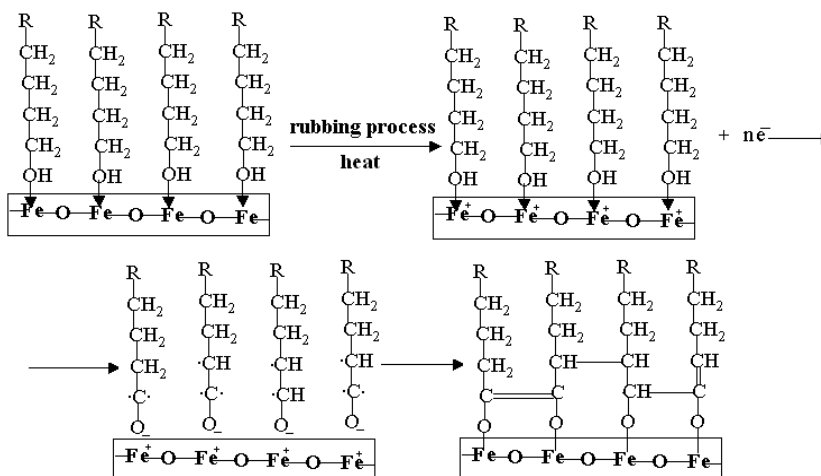
Fig. 4: FTIR spectrum taken from the steel wear track lubricated with 1-decanol (C₁₀) at 80^o C.

The most specific situation arises from the fact that similar peaks were found in spectra taken from aluminum wear tracks lubricated by alcohols [9]. These absorption bands encompass mostly the region of 1520 – 1550 cm⁻¹ with usually is combined with the absorption peaks around 1600 – 1650 cm⁻¹. They have been assigned to organometallic compounds including double bonding.

To account the tribochemicals mechanism of alcohols to form cyclic organometallics with steel surface, the NIRAM approach is applied. According to this approach [8], low energy electrons emitted from steel surface under boundary lubrication conditions interact with alcohols forming negative ions and negative-ion-radicals. Malton and Rudolph [14] demonstrated formation of the following reactive species from alcohols under the interaction with low-energy electrons:



Accordingly, the tribochemical process of steel-on-steel lubricated with decanol may proceed as follows:



CONCLUSIONS

From studying the wear of steel surface under boundary friction condition lubricated with individual alcohols C₁₀, C₁₂ and binary mixtures of these alcohols at different temperatures the following conclusion can be drawn:

1. The minimum wear of steel ball is observed at temperatures 80 °C for individual alcohols and at 40 °C for binary mixtures of these alcohols.
2. The mixture of binary alcohols C₁₀ + C₁₂ is very effective to reduce ball wear compared with individually alcohol C₁₀ and C₁₂.
3. Using FTIR surface analysis new absorption bands were found in deposits formed on the steel substrate. These absorption bands encompass mostly the region of 1522 - 1549cm⁻¹ with usually is combined with the absorption peaks

around 1653 - 1680 cm^{-1} . They have been assigned to organometallic compounds including double bonding. This finding clearly confirms tribochemical reactions of alcohols.

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بحث تأثير درجة الحرارة على تآكل كرة من الصلب مزيته بكحولات أليفاتية وتفاعلاتها الترايبوكيميائية

تعتبر الكحولات الاليفاتية من المواد المستخدمة كمضافات لزيوت التزليق لتحسين خواصها التريبولوجية كمضادات للتآكل ، ولكن ليس هناك معلومات كافية عن آلية عملها. وفي هذا البحث تم دراسة تأثير درجات الحرارة على تآكل كرة من الصلب تتحرك على قرص ثابت من الصلب ومزيته بكحولات (1- ديكانول، 1- دوديكانول) منفردة ومخاليط منها بنسب مولية متساوية.

وقد بينت الدراسة أن أقل تآكل يحدث لكرة الصلب عند درجة حرارة 80 °م في حالة الكحولات المنفردة ، وعند 40 °م في حالة مخاليط هذه الكحولات. أوضح تحليل طيف الأشعة تحت الحمراء للرواسب السطحية المتكونة على سطح القرص الصلب بعد عملية الاحتكاك، أنه في حالة استخدام 1- ديكانول تظهر أحزمة امتصاصية جديدة في المنطقة $1549 - 1522 \text{ cm}^{-1}$ وفي المنطقة $1680 - 1653 \text{ cm}^{-1}$ راجعة إلى تكون مركبات عضوية فلزية تحتوى على روابط مزدوجة.