

Tribochemistry of Various Lubricants on CH_x Coated Disks Using DLC Coated and Uncoated Al₂O₃/TiC Sliders in UHV

Chao-Yuan Chen and D.B. Bogy
Computer Mechanics Laboratory
Department of Mechanical Engineering
University of California, Berkeley, CA 94720

and

C. Singh Bhatia
IBM Corporation, Storage Systems Division
5600 Cottle Road, San Jose, CA 95193

Abstract

We study the wear mechanisms at the head-disk interface of magnetic hard disk systems by use of drag tests in UHV, measuring friction and the spectrum of the gas generated at the interface. The results show that DLC deposited films on the slider's air bearing surfaces can significantly improve the wear durability in sliding against hydrogenated carbon (CH_x) overcoats. Another important result is that the wear durability is significantly improved as the percent of hydrogen in the CH_x overcoats is increased. Finally, lubricant mixtures are also studied. The results show that the lubricants X-1P and Z-Dol can protect each other under drag tests when they are used as a mixture. This report describes the experimental results and attempts to explain why these phenomena occur.

I Introduction

In order to increase areal densities in magnetic disk drives, manufacturers are now experimenting with thin overcoats on the air bearing surfaces of the sliders as well as on the disks. Thin DLC films have recently been deposited on $\text{Al}_2\text{O}_3/\text{TiC}$ sliders, and they have led to very significant improvements in wear durability. Also, hydrogenated carbon overcoats on the disks have shown better wear durability than the pure sputtered carbon. Another recent development is the apparently improved performance by lubricant mixtures. This report presents studies of the tribochemical wear at the head-disk interface by performing drag tests in UHV for various DLC films on sliders, CH_x films on disks, and lubricant mixtures.

There are three parts in this report. The first part is a study of the behavior of DLC coated and uncoated $\text{Al}_2\text{O}_3/\text{TiC}$ sliders on disks with a 5% CH_x overcoat and Z-Dol lubricant. The mechanical properties, such as hardness, of the contacting surfaces have traditionally been viewed as the dominant parameters for determining wear in drag tests. A variety of materials have been deposited on air bearing surfaces to improve the wear durability at the head-disk interface. Studies in vacuum by Pan and Novotny [Ref.1] have compared the tribochemistry of sliders with various deposited overcoat materials including amorphous carbon. Their results showed that different overcoat materials can generate very dissimilar fragments from the interface, which may be related the wear mechanisms at the interface. This part of our study seeks to explain why the DLC coated sliders perform better than uncoated sliders.

In the second part we compare the wear behavior of CH_x overcoats with different hydrogen levels under drag tests. Studies have shown that different levels of hydrogen in the overcoat can result in different atomic bonding in the carbon film. There have also been studies of the effect

of the hydrogen levels on the wear durability during drag tests in air [Ref.2]. Also, the effect of the hydrogen content on the bonding characteristics of perfluorinated lubricant with CH_x films has been shown [Ref.3]. In this part we show that the hydrogen content can influence the chemical interactions between the lubricant layer and the slider materials, as well as the wear durability during drag tests in UHV.

In the last part we compare the wear performance of different lubricants. The questions to be addressed are primarily related to the X-1P lubricant; how does it perform in pure form or in a mixture with Z-Dol? X-1P, a cyclic phosphazene lubricant, is a developed synthetic material of exceptionally low vapor pressure and thermo-oxidative uniformity. The characteristics of the phosphazene lubricants have been presented [Ref.4] and the environmental effects of the phosphazene lubricants on hard disks have also been reported [Ref.5]. One of the uncommon properties of X-1P is that it performs very well as a pure lubricant or in a mixture with other representative lubricants, such as Z-Dol or AM2001. In this part we show that the mixed lubricants perform better than pure Z-Dol or pure X-1P in terms of wear durability and by tribochemical analysis.

II Experiment

2.1 Materials

Thin film magnetic recording disks with sputtered CHx overcoats of 5% and 40% hydrogen in 7.5 nm thickness were used. The films were sputtered from a carbon source onto a disk in a H₂/Ar mixture at a base pressure of 1E-7 Torr. The disks were lubricated with one of three lubricants; Z-Dol, X-1P and 6% X-1P in Z-Dol, all of 8.5Å thickness. The sliders used were 50% Taper Flat Al₂O₃/TiC sliders with or without DLC coating on the air bearing surfaces. The load applied on the sliders was 4 grams.

2.2 Apparatus

Drag tests were carried out inside a stainless-steel ultra high vacuum (UHV) chamber which is fitted with a quadruple mass spectrometer (BALZER). This mass spectrometer can simultaneously detect intensities versus time of at most 15 different atomic mass units (AMU) ranging from 1 to 500. Friction was also monitored along with these mass intensities by using strain gauge transducers. The chamber is equipped with a mechanical pump and a turbo pump (BALZER) for pumping the vacuum.. This turbo pump has a flow rate of 380 liters per second. In the experiments the chamber was first pumped down to the base pressure of 1.5E-8 Torr. Two ion gauges were used to detect the pressure inside the chamber. Thin film disks were mounted on a spindle driven by a DC motor. The slider-suspension systems were mounted on the positioning arm with strain gages that recorded vertical loading on the slider and horizontal friction force as well. A position manipulator allowed adjustment of the location of the slider on the disk. Resistance heating tapes were wrapped around the chamber for baking out the contamination inside the chamber after each drag test. The temperature during baking was around 150 °C. The

measurement data of the mass spectrometer was monitored by a PC through the software package Quadstar 420 (BALZER).

2.3 Procedure

The experimental steps were as follows. First the chamber was baked at high vacuum (around $1\text{E-}7$ Torr) at a fixed temperature of $150\text{ }^{\circ}\text{C}$ for at least 48 hours to completely degas the filaments of the mass spectrometer during the bake-out period. Next, in order to mount the disk and the slider the chamber was back filled with Argon gas to increase the pressure and allow the chamber to be opened. After the parts were mounted the chamber was then pumped down to the base pressure at $1.5\text{E-}8$ Torr, during about 20 hours of pumping. The channels of the mass spectrometer were assigned to the selected masses. The drag tests usually started with a certain period of delay after the mass spectrometer was turned on to obtain the background intensities of the selected masses (AMU). After this period, the spindle was turned on to start the drag tests. The spindle was stopped as soon as wear could be visually detected on the disk, and the mass spectrometer kept on recording the mass intensities for a while before the experiment was terminated. Mass fragment intensities of masses 31 (CF), 47 (CFO), 50 (CF_2), 51 (CF_2H), 66 (CF_2O), 69 (CF_3), 119 (C_2F_5) 112 (F- C_6H_4 -OH) and 162 (CF_3 - C_6H_4 -OH) were recorded versus real time along with the friction measurement.

III Results

3.1 Comparison of Sliders With and Without DLC Coating

Figure 3.1 shows the friction coefficients of the drag tests on Z-Dol lubricated disks with 5% CHx overcoats. In Fig. 3.1 (a), for the uncoated $\text{Al}_2\text{O}_3/\text{TiC}$ slider, the friction coefficient started at 0.28 and remained between 0.2 and 0.37 for 138 revolutions before it became unstable. Very small particles at the head-disk interface wore the real contact region at the interface, and resulted in unstable friction. In Fig. 3.1 (b), for the DLC coated $\text{Al}_2\text{O}_3/\text{TiC}$ slider, the initial friction coefficient started at 0.08, suddenly dropped to 0.03, and then it was very stable between 0.03 and 0.006 for 316 revolutions before the disk was worn. Similarly, the friction coefficient curves on the 5% CHx disks with X-1P and the mixed lubricant are plotted in Fig. 3.2 and in Fig. 3.3, respectively. In Fig. 3.2 (a), for the uncoated $\text{Al}_2\text{O}_3/\text{TiC}$ slider on the X-1P lubricated disks, the original friction coefficient started at 0.48 and then remained between 0.32 and 0.48 for only 30 revolutions before it became unstable. In Fig. 3.2 (b), for the DLC coated $\text{Al}_2\text{O}_3/\text{TiC}$ slider on X-1P lubricated disks, the initial friction coefficient started at 0.14, suddenly dropped to 0.03 and then was stable between 0.02 and 0.06 for just 42 revolutions before the disk was worn. In Fig. 3.3 (a), for the uncoated $\text{Al}_2\text{O}_3/\text{TiC}$ slider on the disks with the mixed lubricant, the friction coefficient started at 0.027, suddenly dropped to 0.015 and then it was stable at 0.015 for 236 revolutions before it dropped and became unstable. In Fig. 3.3 (b), for the DLC coated $\text{Al}_2\text{O}_3/\text{TiC}$ slider on the disks with mixed lubricant, the original friction coefficient started at 0.023, suddenly dropped to 0.013 and then was stable between 0.008 and 0.013 for more than 1096 revolutions before the disk was worn. Comparing these results shown in Fig. 3.1 to Fig. 3.3, we find that the DLC coated sliders show a much better wear durability and lower friction coefficient than the

uncoated sliders for all three lubricants. The coated sliders reduced the friction coefficients by about one order of magnitude for both the Z-Dol lubricated and the X-1P lubricated disks, but not as much for the disks with the mixed lubricant. The slider coating improved the wear durability by 130% (from 138 Revs to 316 Revs) on the Z-Dol lubricated disks, 40% on the X-1P lubricated disks and 360% on the disks with mixed lubricant.

Figure 3.4 shows the mass spectra produced by (a) uncoated and (b) DLC coated $\text{Al}_2\text{O}_3/\text{TiC}$ sliders on the Z-Dol lubricated 5% CHx disks. The spectra are normalized by the strongest mass peak in each drag test. In Fig. 3.4, for the uncoated slider, the highest mass peak is located at mass 51 (CF_2H) followed by mass 47 (CFO) and then mass 69 (CF_3). In Fig. 3.4, for the coated slider, the strongest mass peak is at 47 (CFO) instead of mass 51 (CF_2H), followed by mass 66 (CF_2O) and mass 69 (CF_3). Comparing the mass spectra of the uncoated and coated sliders in Fig. 3.4, we see that the normalized intensities of mass 51 (CF_2H), mass 69 (CF_3) and mass 119 (C_2F_5) were reduced by the coated slider as compared to the uncoated slider. In Fig. 3.5, for the uncoated slider on the X-1P lubricated disk, the highest mass peak was located at mass 69 (CF_3) followed by mass 112 ($\text{F-C}_6\text{H}_4\text{-OH}$) and mass 162 ($\text{CF}_3\text{-C}_6\text{H}_4\text{-OH}$). For the coated slider, the strongest mass peak was still at mass 69 (CF_3), followed by mass 51 (CF_2H) and mass 31 (CF). Comparing the spectra between the uncoated and coated sliders in Fig. 3.5, we see that the normalized intensities of mass 112 ($\text{F-C}_6\text{H}_4\text{-OH}$) and mass 162 ($\text{CF}_3\text{-C}_6\text{H}_4\text{-OH}$) were reduced more than the other mass intensities by coating the slider. In Fig. 3.6, for the uncoated slider on the disks with mixed lubricant, the highest mass peak was located at mass 47 (CFO) followed by mass 69 (CF_3) and mass 66 (CF_2O). For the coated slider, the strongest mass peak was still at mass 47 (CFO) followed by mass 66 (CF_2O) and mass 51 (CF_2H). Comparing the uncoated and

coated slider results in Fig. 3.6, we see that the normalized intensities of mass 69 (CF_3) and mass 119 (C_2F_5) were reduced significantly by coating the slider.

3.2 CH_x Coatings with Two Different Hydrogen Levels

Figure 3.7 shows the friction coefficients of the drag tests performed on the Z-Dol lubricated 40% CH_x disks. In Fig. 3.7 (a), for the uncoated $\text{Al}_2\text{O}_3/\text{TiC}$ slider on the Z-Dol lubricated disk, the initial friction coefficient started at 0.21 and then varied between 0.23 and 0.18 for 180 revolutions before it became unstable. For the DLC coated $\text{Al}_2\text{O}_3/\text{TiC}$ slider on the Z-Dol lubricated disk, the original friction coefficient began at 0.031 and gradually dropped to 0.01, and then it was stable between 0.008 and 0.012 for 492 revolutions before this disk showed a wear track. Comparing the results in Fig. 3.1 and Fig. 3.7, we see that the friction coefficient on the Z-Dol lubricated CH_x coated disks decreased as the hydrogen percentage increased for both the uncoated and coated sliders. The wear durability was also improved significantly by increasing the CH_x percentage for both the uncoated and coated sliders. Figure 3.8 shows the mass spectra produced by the uncoated and coated $\text{Al}_2\text{O}_3/\text{TiC}$ sliders on both 5% and 40% CH_x Z-Dol lubricated disks. The spectra were normalized by the strongest mass peak in each test. In Fig. 3.8 for the uncoated slider on 40% CH_x disks, the highest mass peak is located at mass 47 (CFO) instead of at mass 51 (CF_2H) as on the 5% CH_x disks in Fig. 3.4, and it is followed by mass 51 (CF_2H) and mass 66 (CF_2O). In Fig. 3.8 for the coated slider, the highest mass peak is located at mass 47 (CFO), the same as on the 5% CH_x disks, and it is followed by mass 66 (CF_2O) and mass 51 (CF_2H). Comparing the mass spectra of the uncoated and coated sliders in Fig. 3.8 on the 40% CH_x disks, we see that the normalized intensities of mass 51 (CF_2H), mass 69

(CF₃) and mass 119 (C₂F₅) were reduced significantly for the coated slider, the same result as on the 5% CH_x disks.

3.3 Comparison of Disks with Three Different Lubricants

Figure 3.9 shows the relative average friction coefficients before wear of the 5% CH_x disks with the three different lubricants, and with sliders with and without DLC coatings. In Fig. 3.9, the data shows that the disks with mixed lubricant had lower friction coefficients (0.0136 with the uncoated slider, compared to 0.0121 for the coated slider) than both the Z-Dol lubricated disks (0.25 for the uncoated slider and 0.015 for the coated slider) and the X-1P lubricated disks (0.309 for the uncoated slider and 0.044 for the coated slider). Figure 3.10 shows the same trend for the relative average friction coefficients before wear of the 40% CH_x disk as in Fig. 3.9 for the 5% CH_x disk. The average friction coefficients for all three lubricants and both sliders were reduced about 30~50% when the percentage of hydrogen content in the CH_x was increased from 5% to 40%. Figures 3.11 and 3.12 show the relative number of drag revolutions before wear of the 5% and 40% overcoats for the three different lubricants, respectively, for both the uncoated and coated sliders. In Fig. 3.11, the data shows that the disks with the mixed lubricant had better wear durability (236 Revs for the uncoated slider as compared to 1096 Revs for the coated slider) than both the Z-Dol lubricated disks (138 Revs for the uncoated slider and 316 Revs for the coated slider) and the X-1P lubricated disks (30 Revs for the uncoated slider and 42 Revs for the coated slider). Figure 3.12 shows the same trend. Comparing Fig. 3.11 and 3.12, we see that the wear durability is better when the hydrogen level is increased from 5% to 40%. Figure 3.13 shows the un-normalized mass average intensities from the first 40 dragging revolutions on the Z-Dol lubricated disks and on the disks with the mixed lubricant. In Fig. 3.13, we see that all

fragment intensities were reduced by at least one order of magnitude by the mixed lubricant as compared to the pure Z-Dol lubricant. From this observation, we conclude that the mixed lubricant performed better than pure Z-Dol.

IV Discussion and Conclusions

The CHx disks with different lubricants were drag tested in UHV with both uncoated and DLC coated $\text{Al}_2\text{O}_3/\text{TiC}$ sliders. The coated slider shows a much better wear durability and lower friction coefficient than the uncoated slider. In Fig. 3.4, comparing the relative normalized intensities of mass 47 (CFO) and mass 66 (CF_2O), which are believed to be contributed by thermal desorption means when under mechanical sliding [Ref.6], with those of mass 69 (CF_3) and mass 119 (C_2F_5), which are due to the catalytic reaction [Ref.6] at the head-disk interface, we see that catalytic reaction between the Z-Dol and Al_2O_3 was significantly decreased by coating the slider. The advantage of the carbon coated slider can only be understood when a layer of lubricant is applied on the disk surface. This layer of lubricant helps the carbon coated slider protect the disk overcoat better than the uncoated slider [Ref.7]. In Fig. 3.5, the normalized intensities of mass 112 ($\text{F-C}_6\text{H}_4\text{-OH}$) and 162 ($\text{CF}_3\text{-C}_6\text{H}_4\text{-OH}$), which could possibly be due to the catalytic reaction between X-1P and Al_2O_3 , were also significantly reduced for the coated slider. Therefore, the carbon coated slider protected the overcoat with the X-1P lubricant as well. In Fig. 3.6, we observe that the same trend occurred on the disks with the mixed lubricant.

Comparing Fig. 3.1 with Fig. 3.7, we observe that the friction coefficients on the Z-Dol lubricated CHx coated disks decreased as the hydrogen percentage increased for both the uncoated and coated sliders. One explanation is that the increased hydrogen content satiates the dangling

bonds of the carbon atoms at the overcoat interface and reduces direct interactions at the interface [Ref.8], resulting in a decreased friction coefficient and a much better wear durability. In Fig. 3.8, we see that the normalized intensities of mass 69 (CF_3) and mass 119 (C_2F_5) are higher than that of mass 66 (CF_2O) on the 5% CHx coated disks, but those of mass 69 (CF_3) and mass 119 (C_2F_5) were lower than that of mass 66 (CF_2O) on the 40% CHx coated disks. From these results it can be concluded that the higher level of the hydrogen content in the overcoat can help the sliding interface resist the catalytic effect between Z-Dol and Al_2O_3 , resulting in a better wear durability and a better friction performance. Figure 3.8 showed a consistent result between the 5% and 40% CHx disks with uncoated and coated sliders.

From Fig. 3.9 to Fig. 3.12, we see that the mixed lubricant had better wear durability and a lower friction coefficient than pure Z-Dol or pure X-1P. Comparing Fig. 3.5 with Fig. 3.6, we observe that the normalized intensities of mass 112 ($\text{F-C}_6\text{H}_4\text{-OH}$) and mass 162 ($\text{CF}_3\text{-C}_6\text{H}_4\text{-OH}$), which indicate the catalytic reaction between X-1P and Al_2O_3 , was reduced to a very low level for the mixed lubricant as compared to pure X-1P. One possible explanation is that the Z-Dol protected the slider from catalyzing the decomposition of X-1P at the interface, resulting in a reduced friction coefficient and much better wear performance. On the other hand, X-1P is also used as a mixture with Z-Dol to pacify the head from catalytic reaction with Z-Dol. In Fig. 13, we see that all fragment intensities have been reduced by at least one order of magnitude for the mixed lubricant as compared to pure Z-Dol. From this observation, we can conclude that X-1P also protected Z-Dol from the catalytic reaction at the interface, and therefore the mixed lubricant performed better than pure Z-Dol or pure X-1P, both on wear durability and on friction behavior.

The results presented here show that optimized slider-disk interfaces for wear durability require appropriate combinations of lubricants and slider-disk surface materials.

V Acknowledgment

The research was supported by the Computer Mechanics Laboratory at the University of California at Berkeley. It was also supported by the IBM Corporation

VI References

- [1]. Pan, X. and Novotny, V. J., 1994, "Head Material Effects on Interface Tribochemistry", IEEE Transactions on Magnetics, Vol. 30, No. 2, pp 433-439, March, 1994
- [2]. Lee, J. K., Smallen, M., Enguro., Lee, H. J. and Chao, A., 1993, "The effect of Chemical and Surface Properties of Hydrogenated Carbon Overcoats on the Tribological Performance of Rigid Magnetic Disks", IEEE Transactions on Magnetics, Vol. 29, NO. 1, pp 276-281
- [3]. Perry, S. S., Mate, C. M., White, R. L., and Somorjai, G. A., 1996, "Bonding and Tribological Properties of Perfluorinated Lubricants and Hydrogenated Amorphous Carbon Films", IEEE Transactions on Magnetics, Vol. 32, No. 1, pp 115-121, Jan., 1996
- [4]. Nader, B. S., Kar, K. K., Morgan, T. A., Pawloski, C. E., and Dilling, W. L., "Development and Tribological Properties of New Cyclotriphosphazene High Temperature Lubricants for Aircraft Gas Turbine Engines", STLE Tribology Transaction, J. of Tribology, 35, 1, pp.37-44, 1992
- [5]. Min Yang., Frank E. Talke., D. J. Perettie., T. A. Morgan and K. K. Kar., "Environmental Effects on Phosphazene Lubricated Computer Hard Disks", IEEE Transactions on Magnetics, Vol. 30, NO. 6, pp 4143-4145, Nov., 1994

- [6]. Kasai, P.H., Tang, W.T., Wheeler, P., 1991a, "Degradation of Perfluoropolyethers Catalyzed by Aluminum Oxide", *Applied Surface Science*, Vol. 51, pp201-211
- [7]. Yun, X., Bogy, D. B. and Bhatia, C. S., 1996a, "Wear of Hydrogenated Carbon Disks by Carbon Coated and Uncoated Al₂O₃/TiC Sliders in Ultra High Vacuum", *IEEE Transactions on Magnetics*, to appear in Sept. 1996.
- [8]. Yun, X., Bogy, D. B. and Bhatia, C. S., 1996b, "Tribochemical Study of Hydrogenated Carbon Coatings with Different Hydrogen Content Levels in Ultra High Vacuum", Technical Report No.96-003, Computer Mechanics Laboratory, U.C. Berkeley

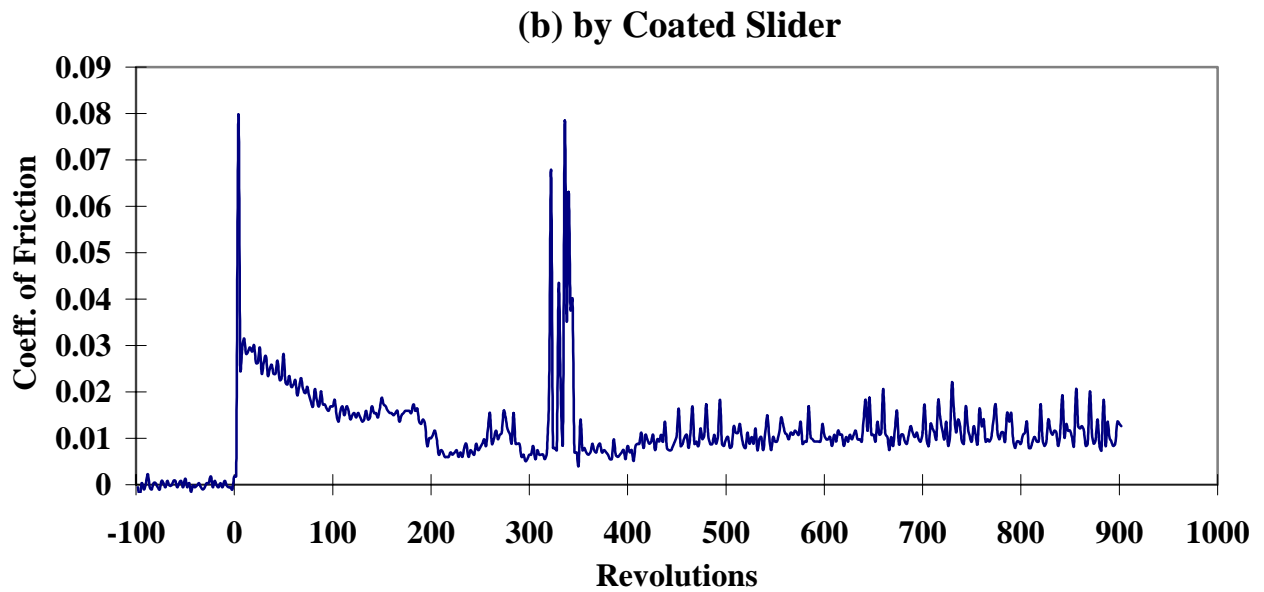
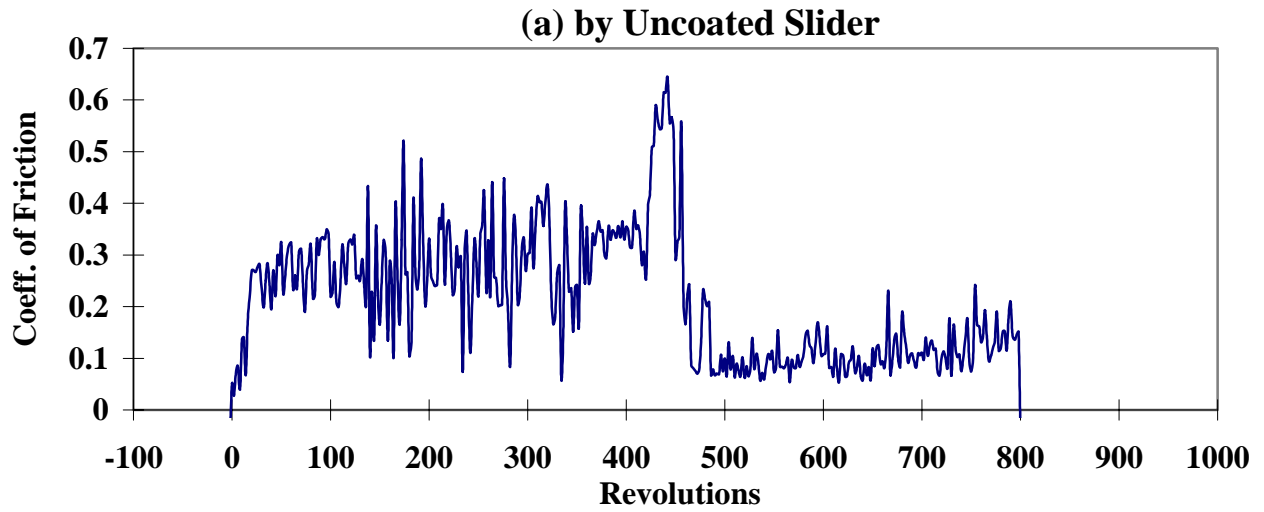


Fig 3.1 Drag tests of uncoated (a) and coated (b) $\text{Al}_2\text{O}_3/\text{TiC}$ sliders on Z-Dol lubricated 5% CH_x disks. Friction were recorded versus real time.

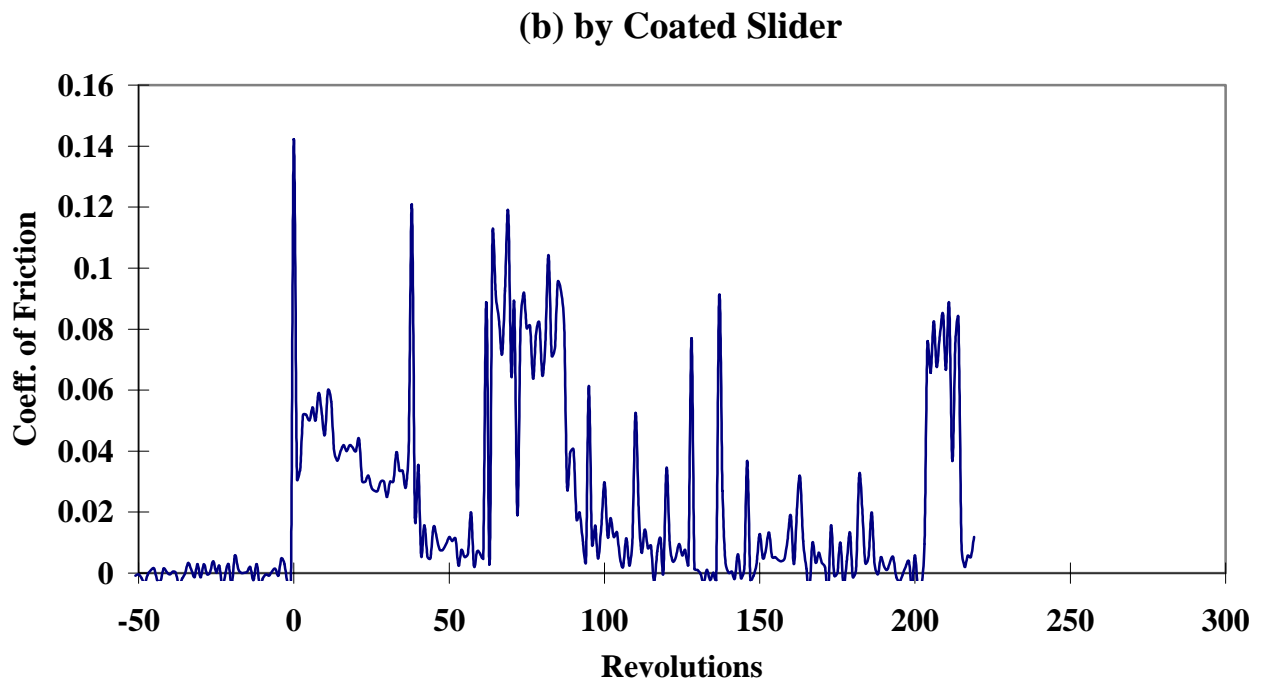
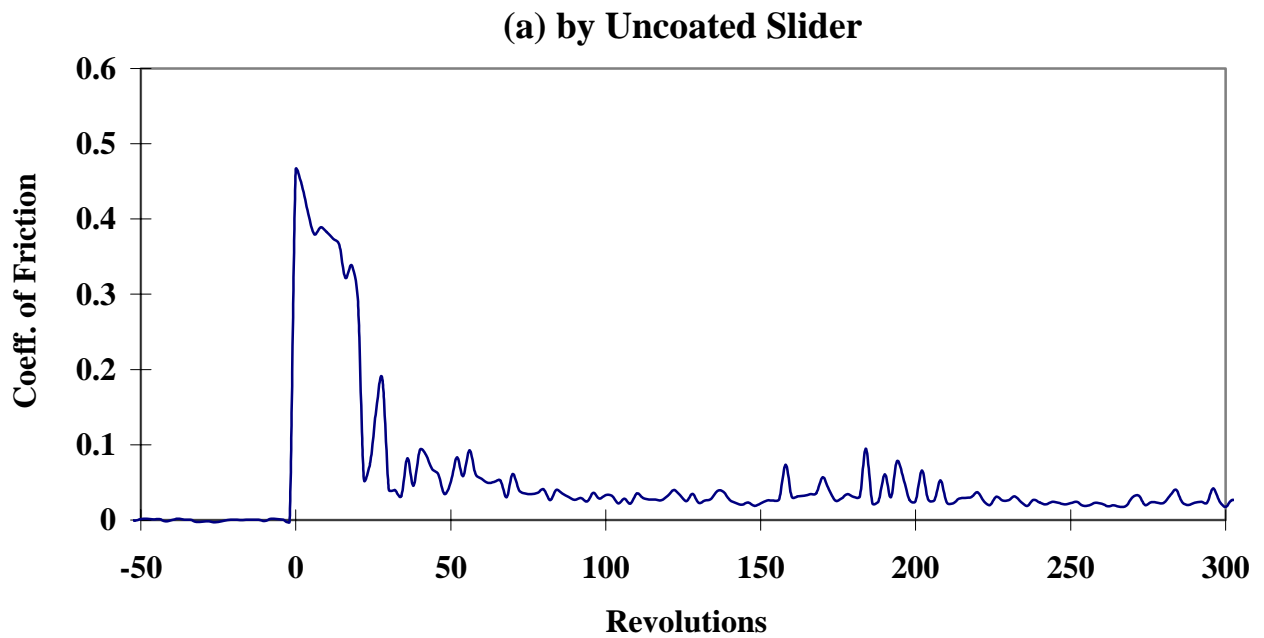
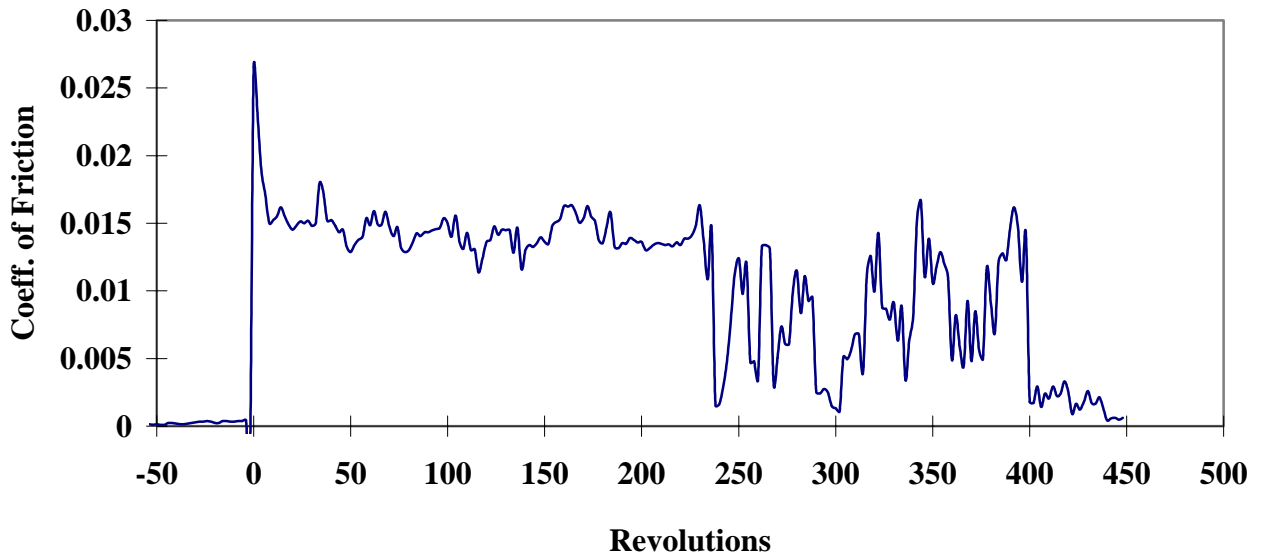


Fig 3.2 Drag tests of uncoated (a) and coated (b) $\text{Al}_2\text{O}_3/\text{TiC}$ sliders on X-1P lubricated 5% CH_x disks. Friction were recorded versus real time.

(a) by Uncoated Slider



(b) By Coated Slider

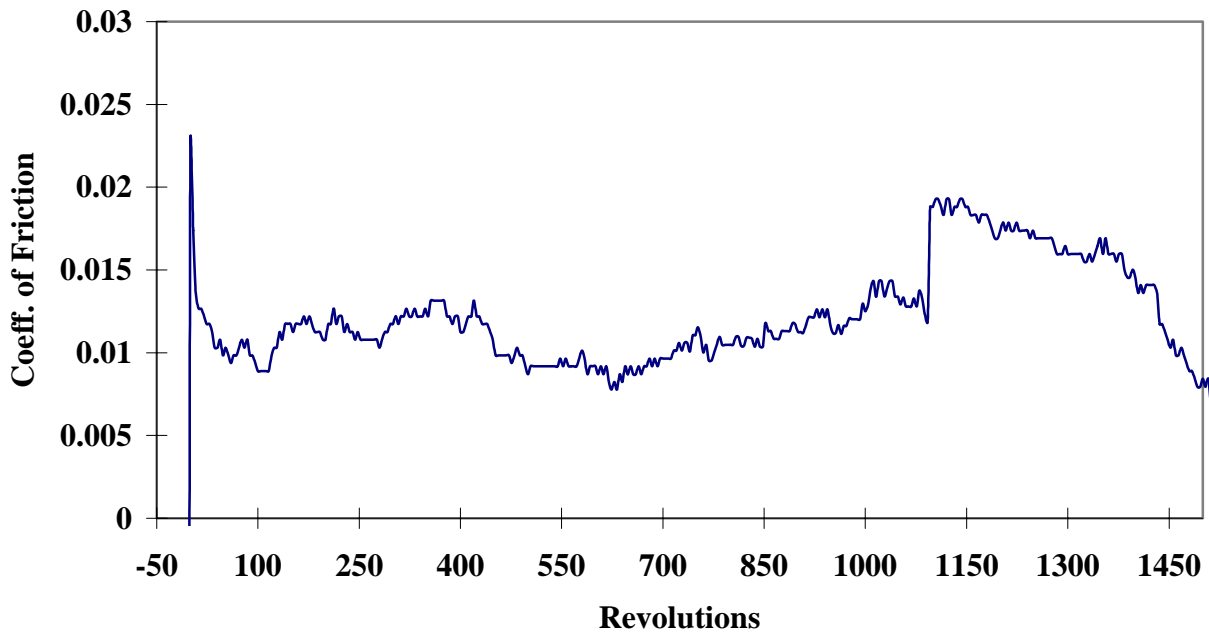


Fig 3.3 Drag tests of uncoated (a) and coated (b) $\text{Al}_2\text{O}_3/\text{TiC}$ sliders on lubricated 6% X-1P Z-Dol lubricated 5% CH_x disks. Friction were recorded versus real time.

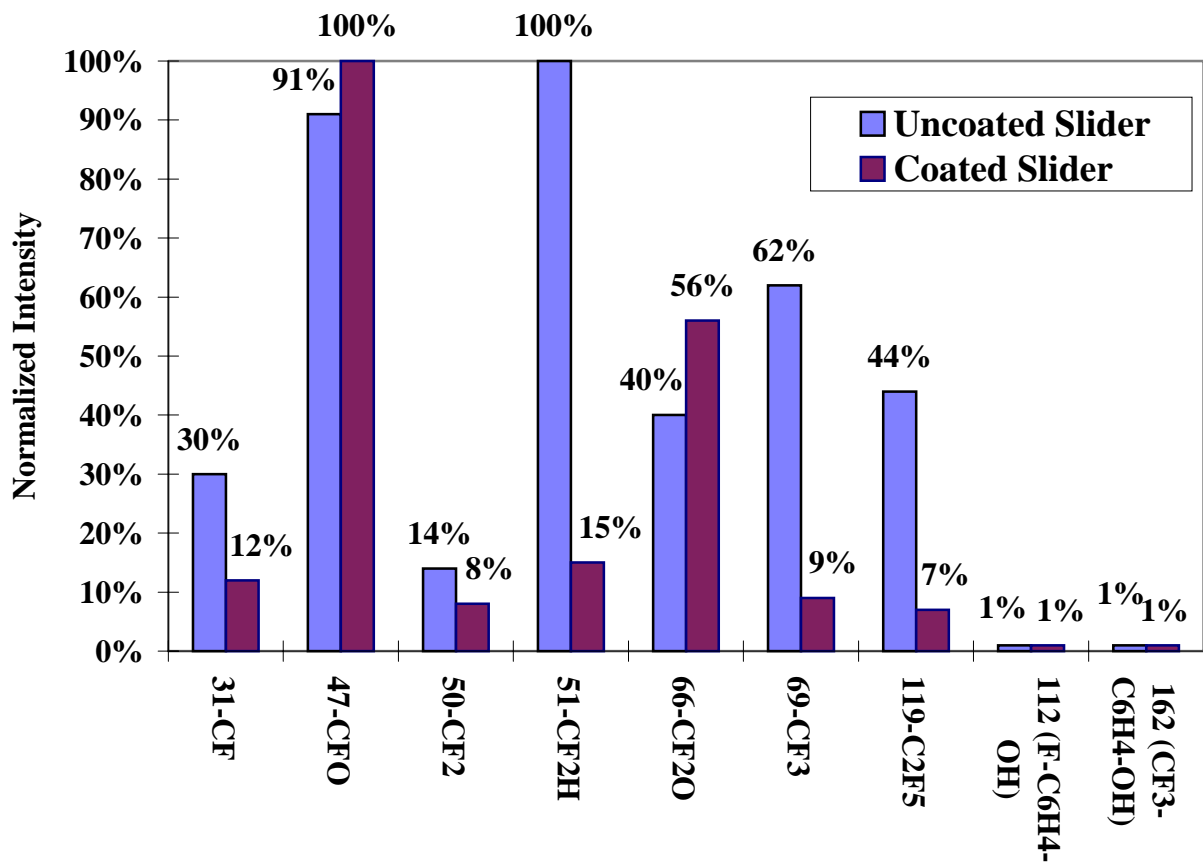


Fig 3.4 Mass spectra produced by uncoated (a) and coated (b) Al₂O₃/TiC sliders on Z-Dol lubricated 5% CH_x disks. The recorded mass fragments were: mass 31 (CF), mass 47 (CFO), mass 50 (CF₂), mass 51 (CF₂H), mass 66 (CF₂O), mass 69 (CF₃), mass 119 (C₂F₅), mass 112 (F-C₆H₄-OH) and mass 162 (CF₃-C₆H₄-OH).

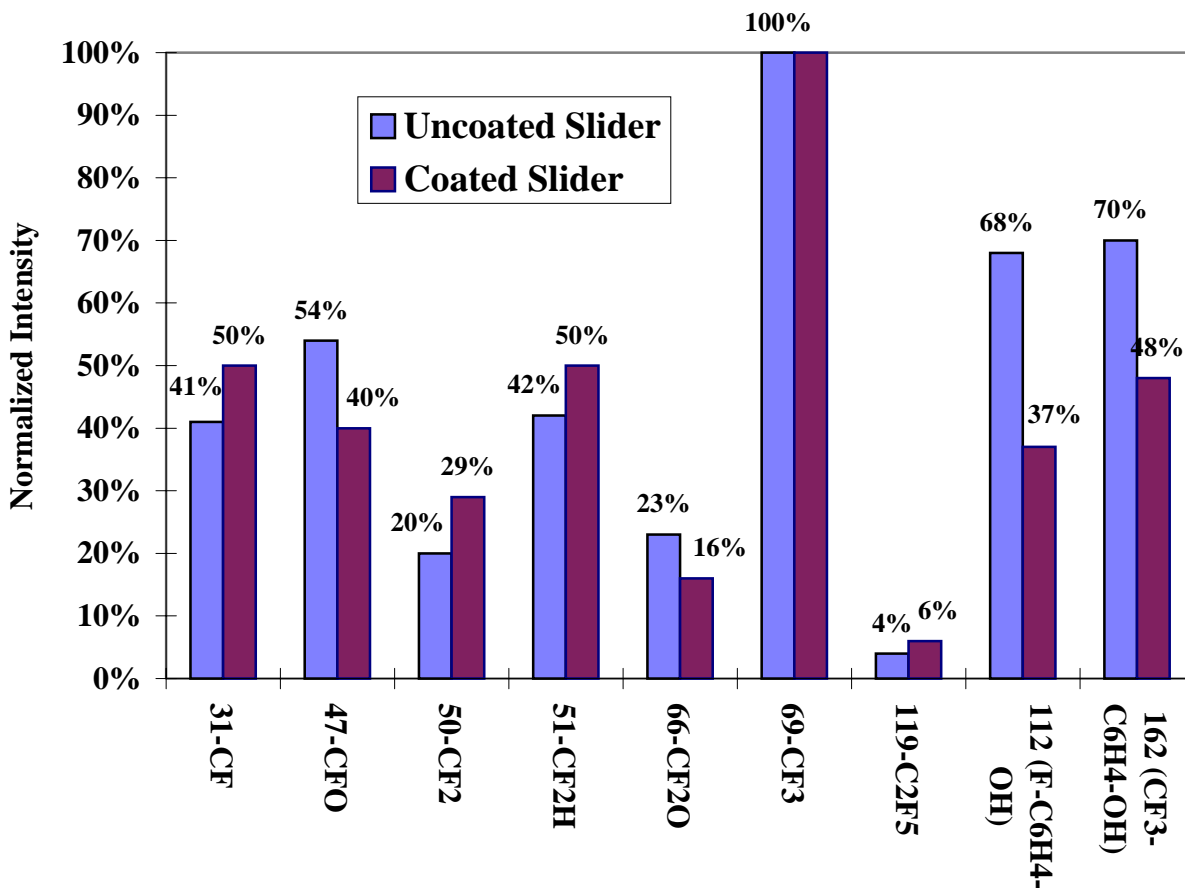


Fig 3.5 Mass spectra produced by uncoated (a) and coated (b) $\text{Al}_2\text{O}_3/\text{TiC}$ sliders on X-1P lubricated 5% CH_x disks. The recorded mass fragments were: mass 31 (CF), mass 47 (CFO), mass 50 (CF_2), mass 51 (CF_2H), mass 66 (CF_2O), mass 69 (CF_3), mass 119 (C_2F_5), mass 112 (F- C_6H_4 -OH) and mass 162 (CF_3 - C_6H_4 -OH).

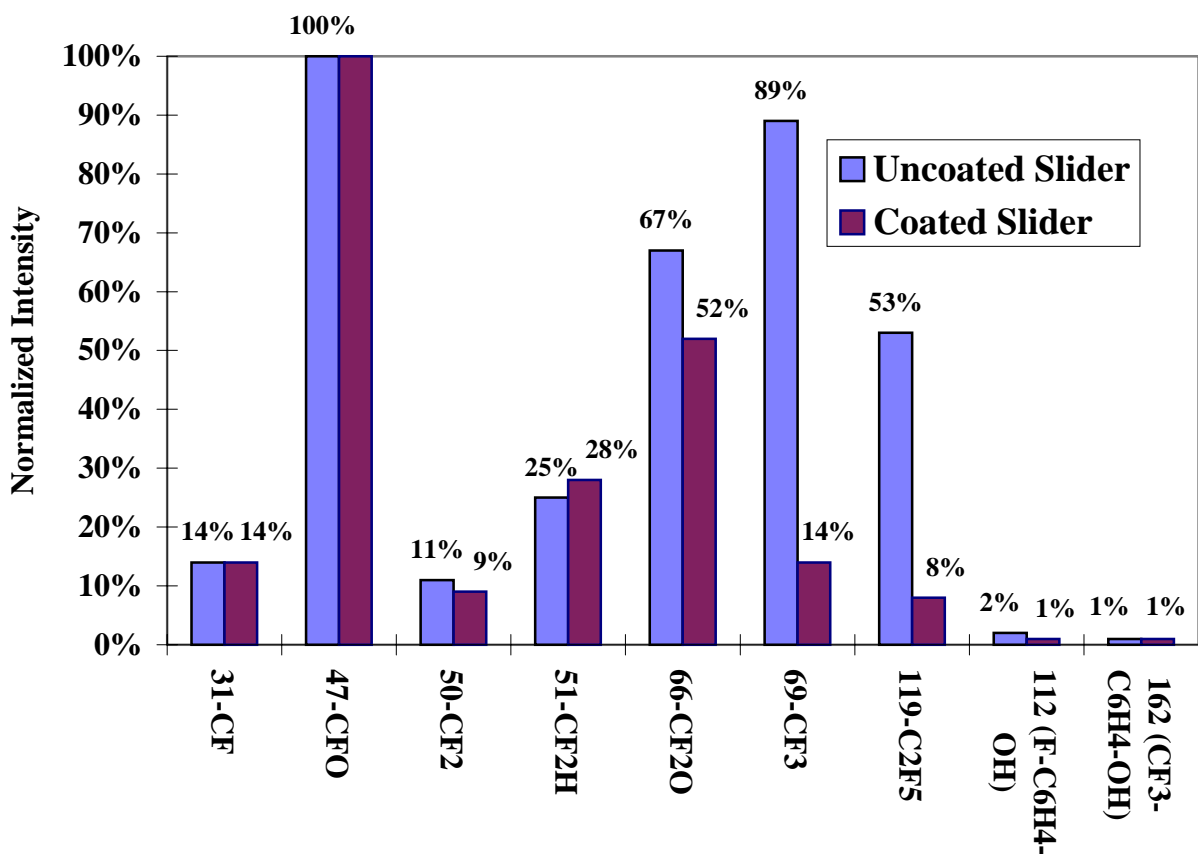
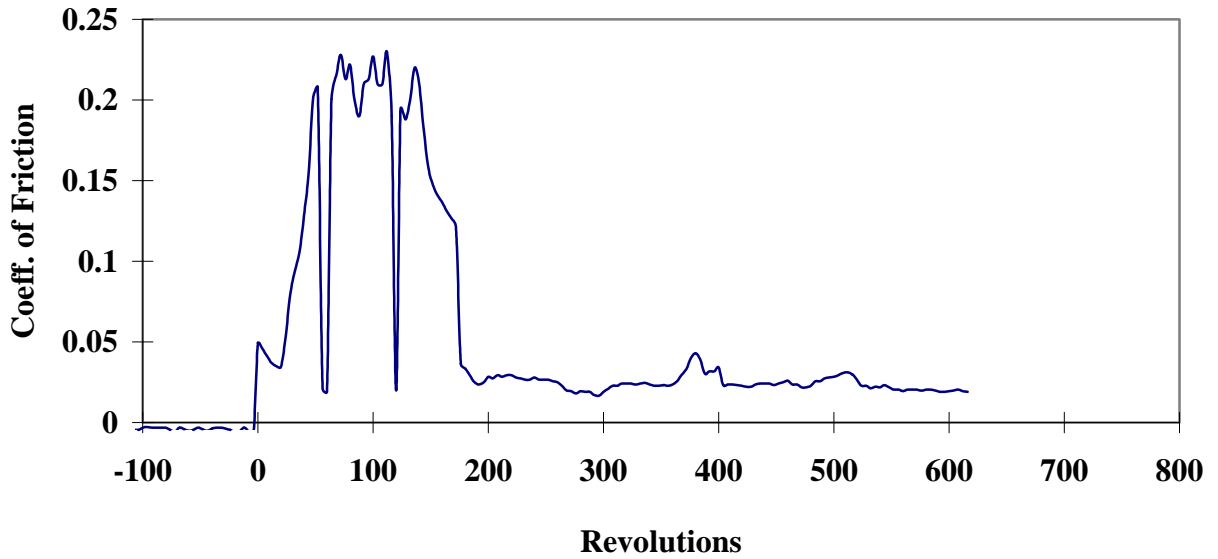


Fig 3.6 Mass spectra produced by uncoated (a) and coated (b) Al₂O₃/TiC sliders on lubricated 6% X-1P Z-Dol lubricated 5% CH_x disks. The recorded mass fragments were: mass 31 (CF), mass 47 (CFO), mass 50 (CF₂), mass 51 (CF₂H), mass 66 (CF₂O), mass 69 (CF₃), mass 119 (C₂F₅), mass 112 (F-C₆H₄-OH) and mass 162 (CF₃-C₆H₄-OH).

(a) by Uncoated Slider



(b) by Coated Slider

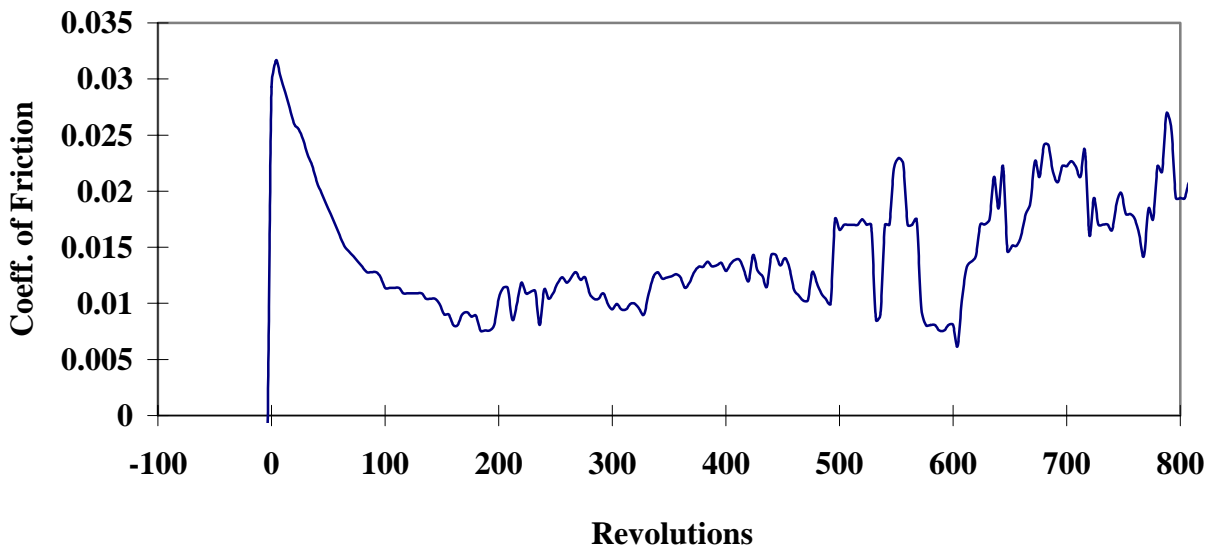


Fig 3.7 Drag tests of uncoated (a) and coated (b) $\text{Al}_2\text{O}_3/\text{TiC}$ sliders on Z-Dol lubricated 40% CHx disks.

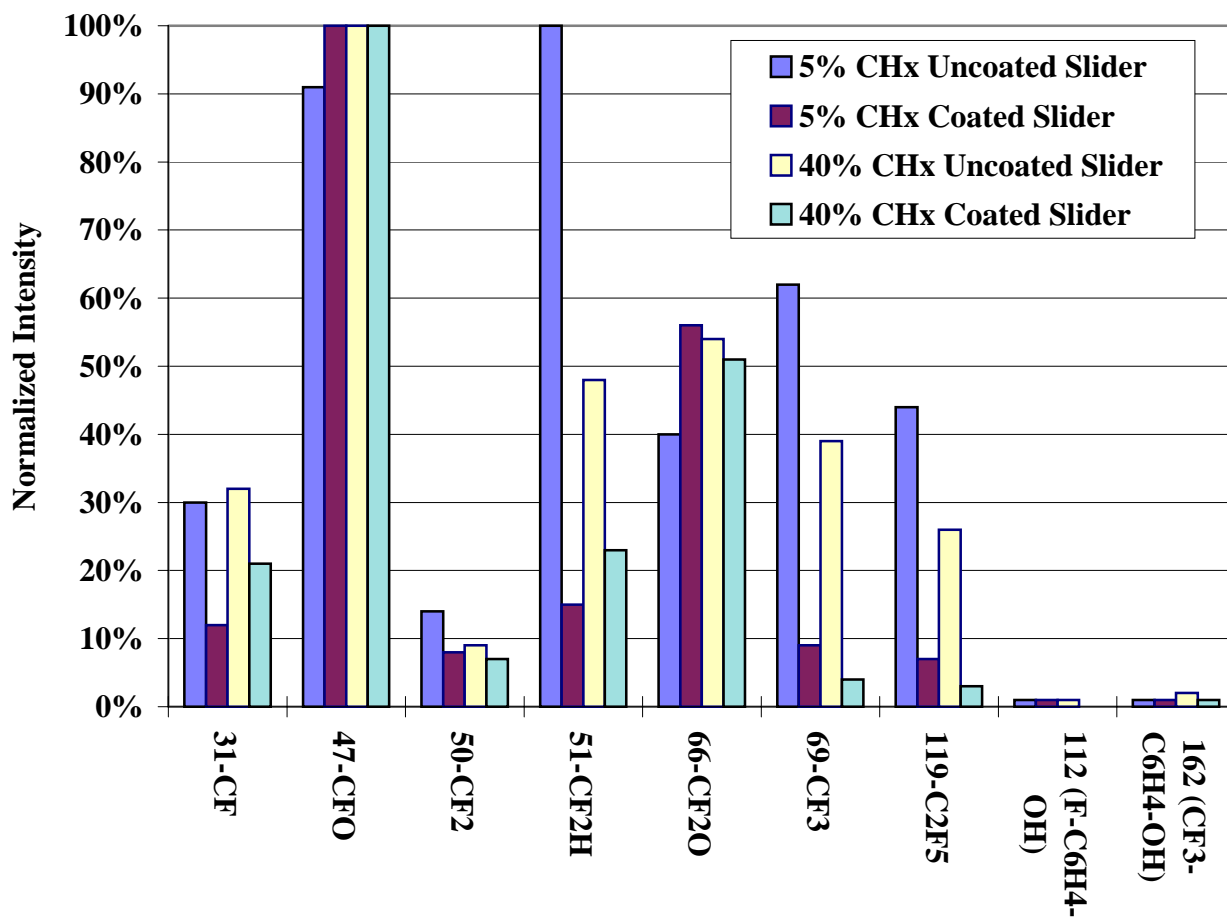


Fig 3.8 Relative intensities of Z-Dol fragments produced by dragging uncoated and coated Al₂O₃/TiC sliders on CHx 40% dosks. The recorded mass fragments were: mass 31 (CF), mass 47 (CFO), mass 50 (CF₂), mass 51 (CF₂H), mass 66 (CF₂O), mass 69 (CF₃) and mass 119 (C₂F₅).

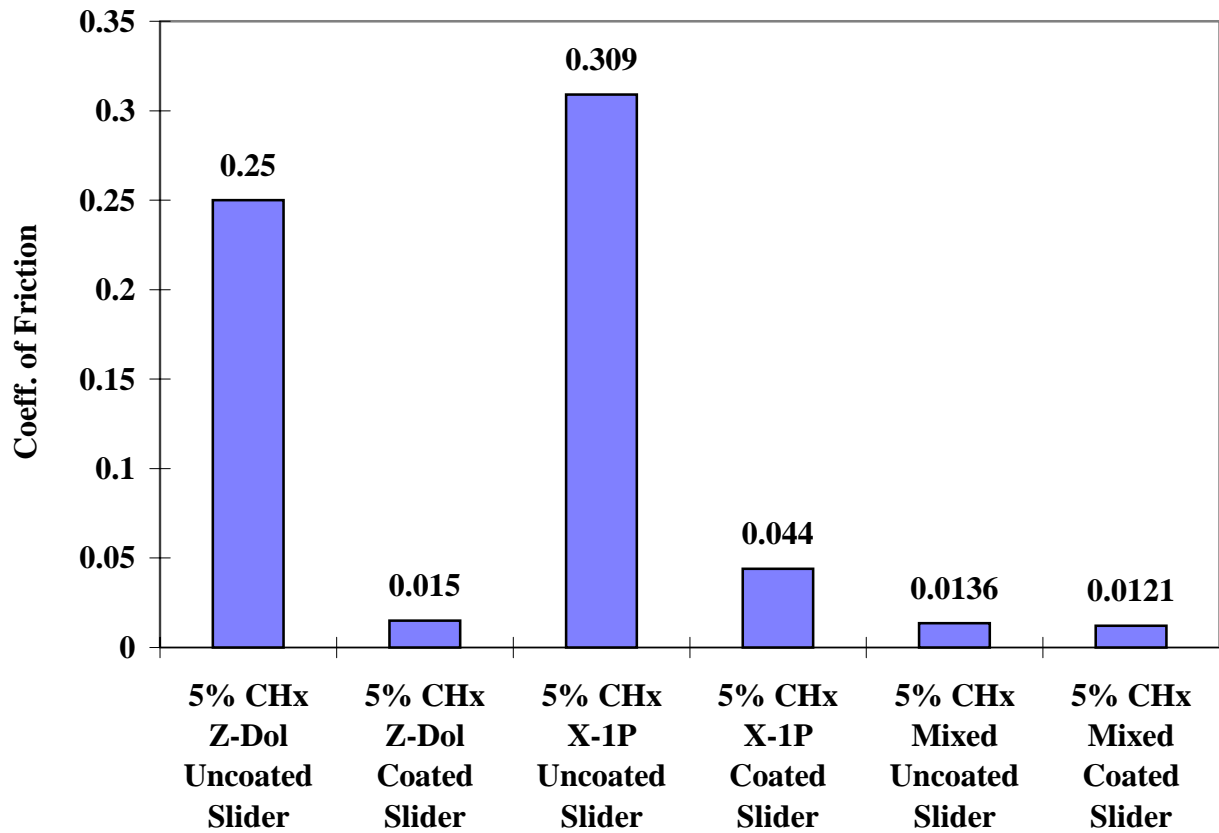


Fig 3.9 Relative average friction coefficients before wear of 5% CHx disks with different lubricants by with and without CHx coating Al₂O₃/TiC sliders during drag tests.

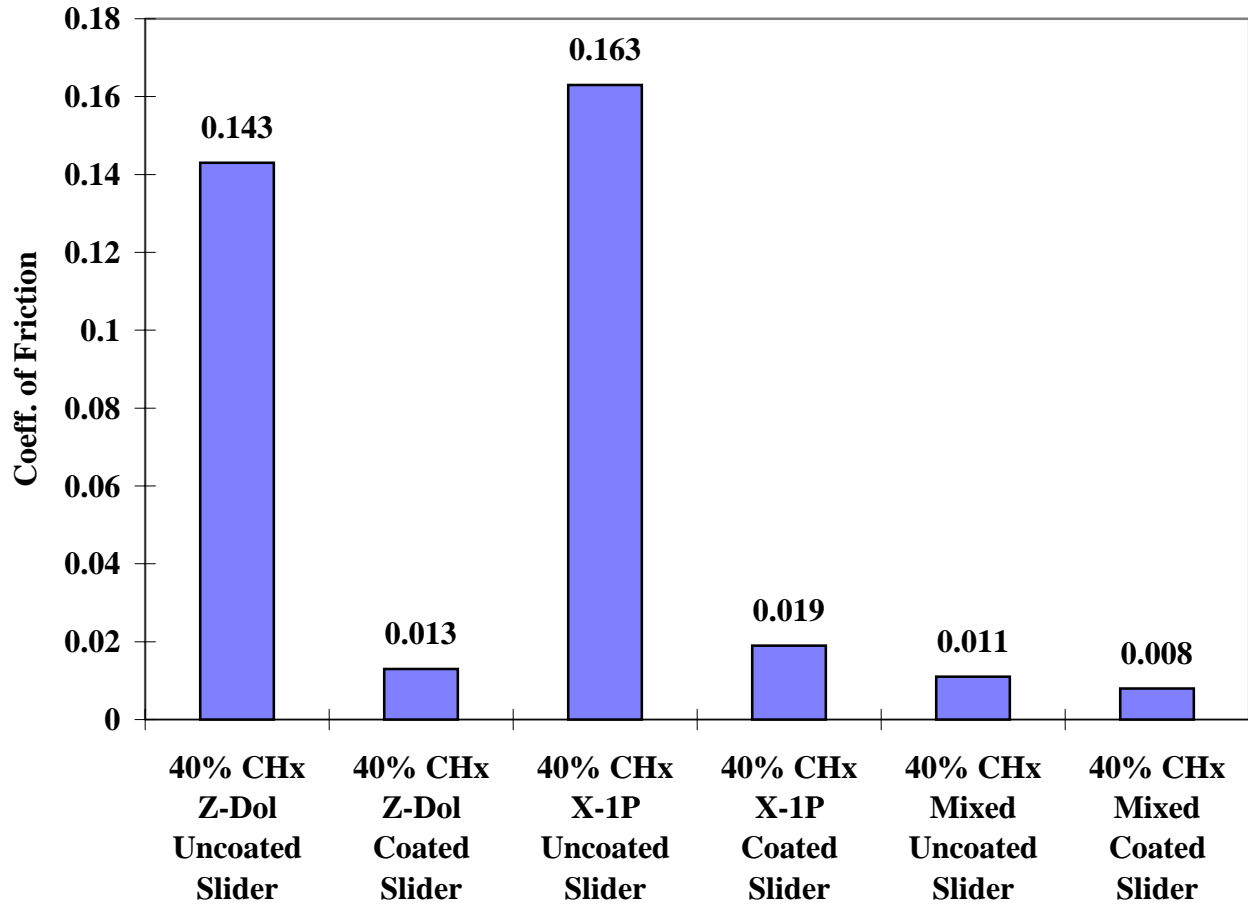


Fig 3.10 Relative average friction coefficients before wear of 40% CHx disks with different lubricants by with and without CHx coating Al₂O₃/TiC sliders during drag tests.

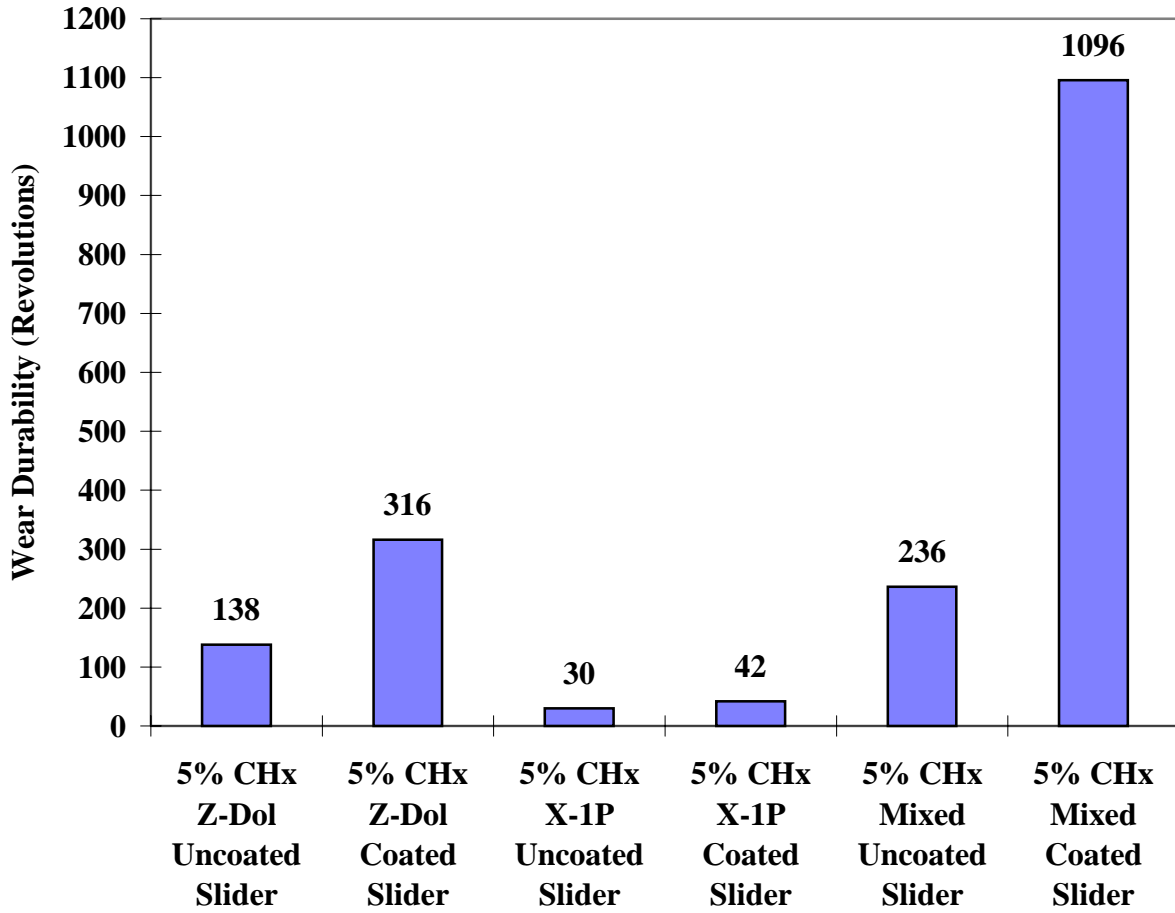


Fig 3.11 Relative number of drag revolutions before wear of 5% CHx disks with different lubricants by with and without CHx coating Al₂O₃/TiC sliders during drag tests.

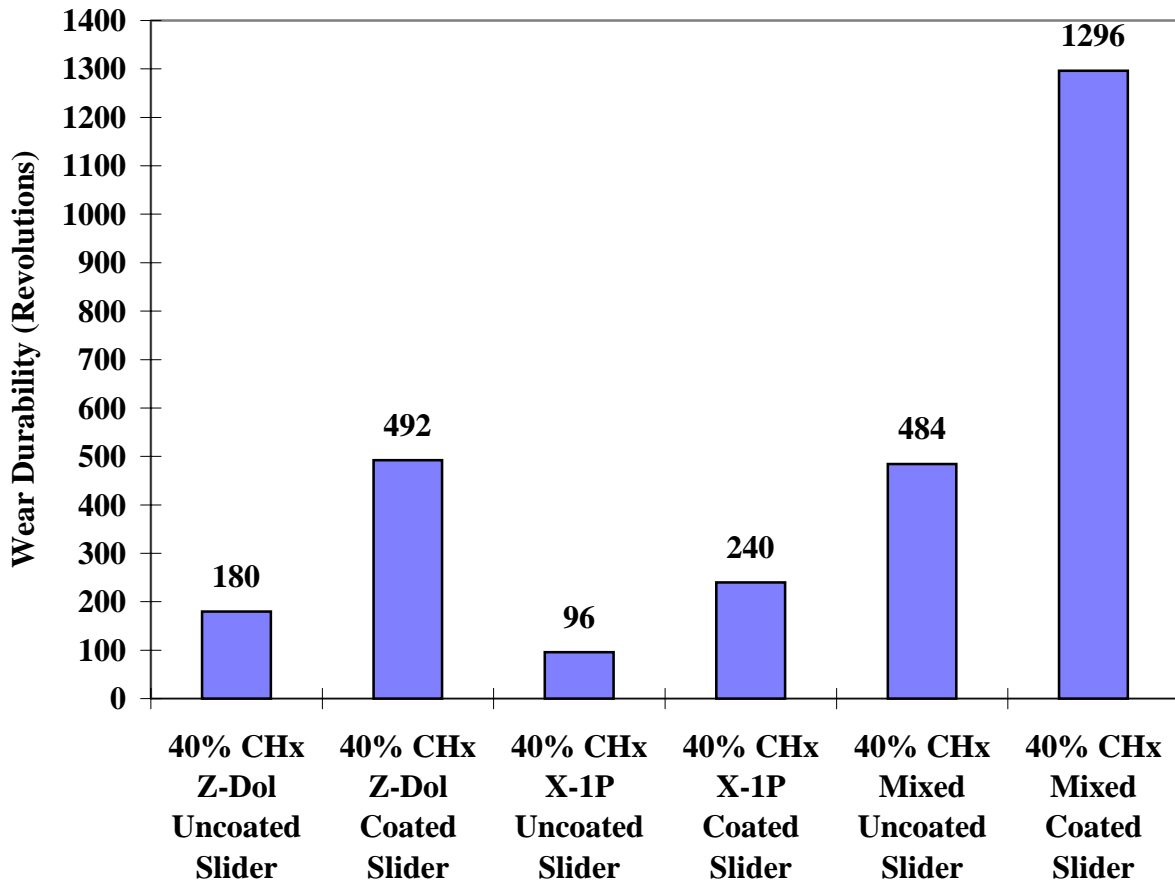


Fig 3.12 Relative number of drag revolutions before wear of 40% CHx disks with different lubricants by with and without CHx coating Al₂O₃/TiC sliders during drag tests.

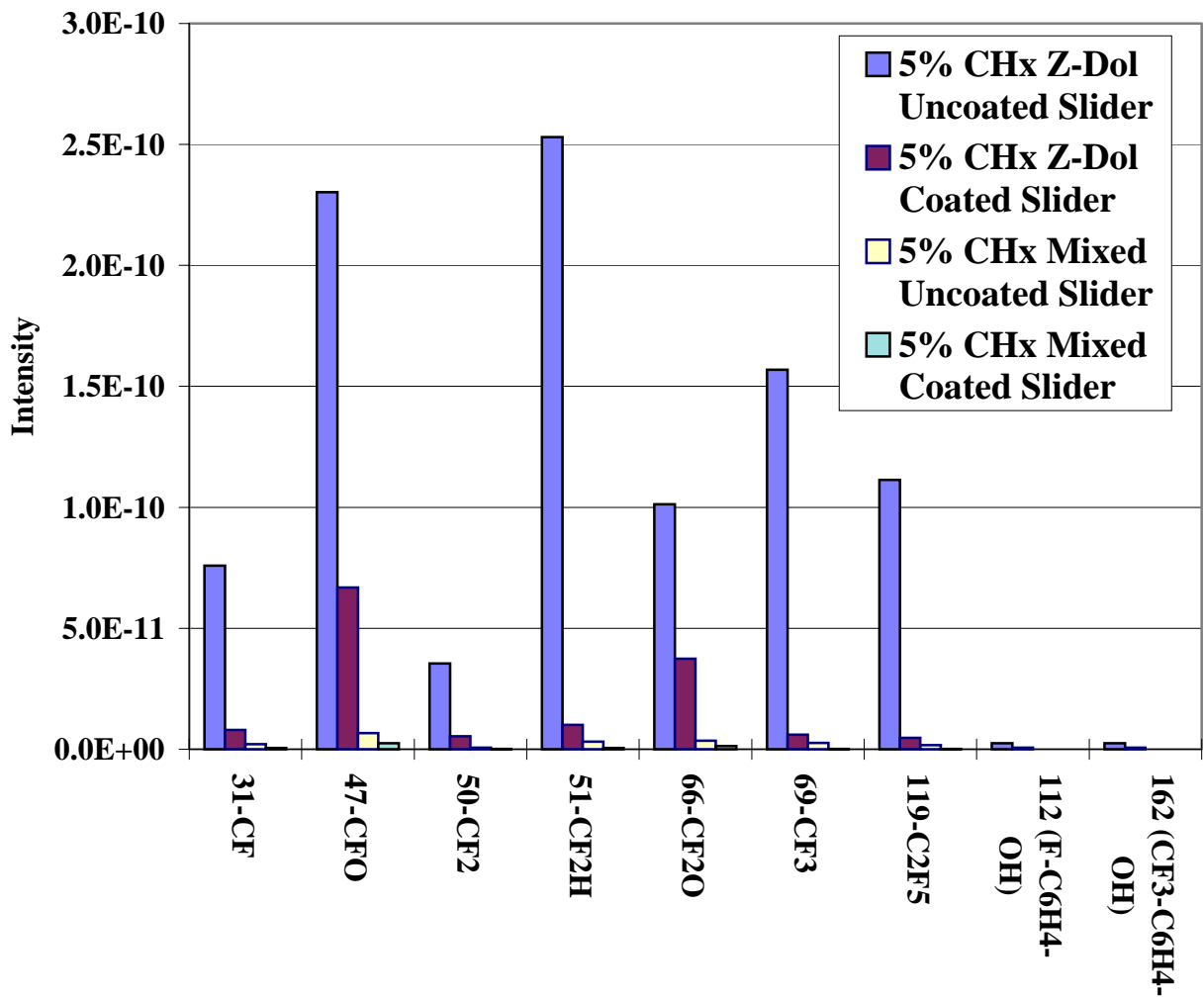


Fig. 3.13 The relative average intensities of mass fragments of Z-Dol and 6% X-1P Z-Dol on 5% CHx disks by uncoated and coated sliders.