Surface Energy of Counter Sample on Tribological Performance of Etched and Unetched PTFE Composites

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Abstract

PTFE-based composites are widely used as low-friction, wear-resistant materials in aerospace, automotive, and industrial applications. This study investigates the impact of fluoroetching and counter-surface energy on the tribological performance of pure PTFE 7AX and PTFE filled with 5% alumina (Al_2O_3) by weight. Unetched and fluoroetched specimens of both materials were tested against glass, charged glass, and stainless steel counter-surfaces of varying surface energies using a reciprocating tribometer under controlled laboratory conditions. Contact angle measurements and the Owens–Wendt method were used to quantify surface energy across all samples and counter-surfaces. Results identify how counter-surface energy, alumina addition, and fluoroetching collectively influence wear resistance and friction coefficient.

Introduction

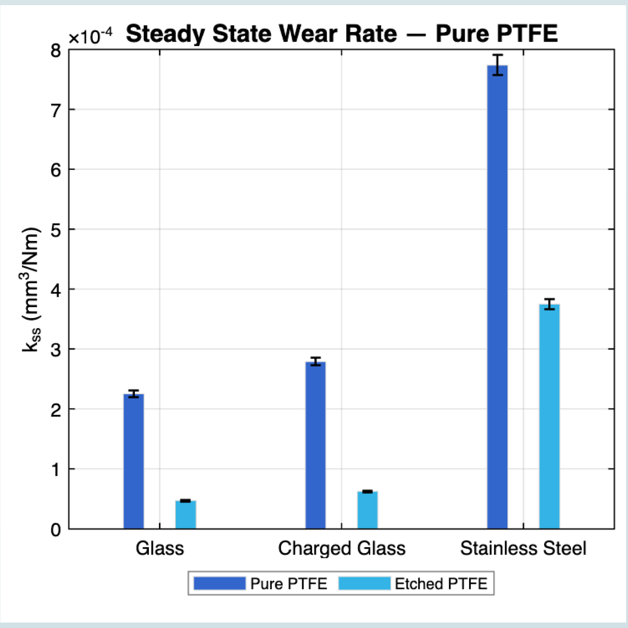
Polytetrafluoroethylene (PTFE) is widely used in aerospace, automotive, and industrial applications for its low friction, chemical resistance, and thermal stability. However, PTFE wears out quickly under sliding contact, causing significant material loss over time.

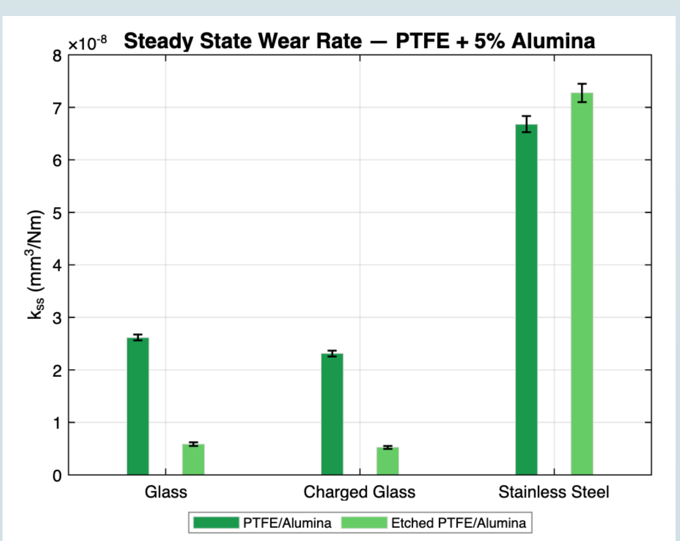
Adding just 5% alumina (Al_2O_3) by weight reduces PTFE wear by over four orders of magnitude.[1,2] As the surfaces slide, mechanical stress breaks PTFE chain bonds, creating reactive end groups that bond to the counter-surface and form a thin, protective film.[2] The alumina particles also scrub surface oxides off the metal, enabling stronger film adhesion.[2]

Initially wear is high during run-in, but once the film stabilizes the system reaches steady state. Wear rate is reported as $k = V/(F_n \cdot d)$, where V is volume loss (mm³), F_n is normal force (N), and d is sliding distance (m), giving units of mm³/Nm. The tradeoff is that alumina slightly increases steady state friction.[1]

Surface energy describes how two surfaces interact when sliding and is split into dispersive (γ^d) and polar (γ^p) components.[3] PTFE is almost entirely dispersive with near-zero polar character. Three counter-surfaces of varying surface energies were selected: stainless steel, standard glass, and charged glass, a positively charged surface commonly used to promote strong adhesion.[4] Surface energies are reported in the results.

Fluoroetching treats PTFE with sodium naphthalenide, replacing C−F bonds with C=C bonds and raising surface energy without affecting bulk properties.[5] Surface energy was quantified via contact angle measurements using the Owens–Wendt method.[3]





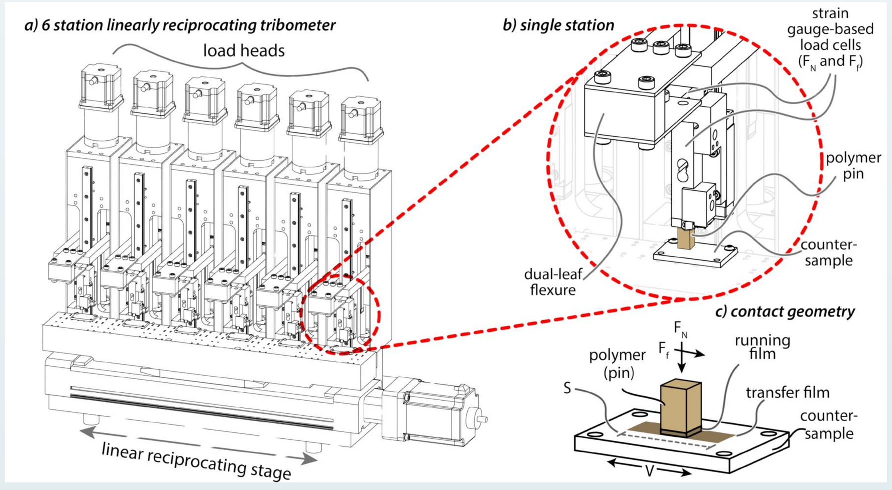
Methodology

Sample Preparation

- Four polymer mixtures were prepared: pure PTFE 7AX, fluoroetched PTFE 7AX, PTFE + 5% Al_2O_3, and fluoroetched PTFE + 5% Al_2O_3
- Composite powders were added to IPA and mixed via sonication in three 5-minute intervals; IPA was allowed to fully evaporate
- After drying, mixtures were placed into a cylindrical mold and compressed under a 25 kN load for one minute
- Cylinders were sintered at 500°C on a controlled heating curve and machined into 6.25 × 6.25 × 12.5 mm rectangular prisms

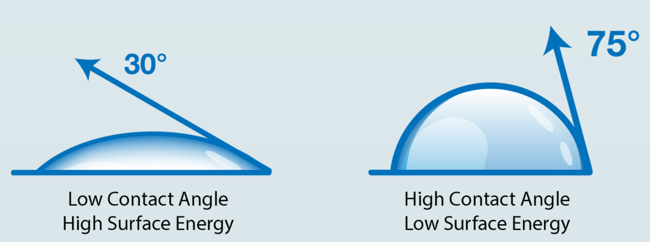
Tribometer Testing

- Samples were loaded into a reciprocating tribometer with a normal load of 250 N applied against glass, charged glass, or stainless steel
- Samples underwent multiple sets of 40 mm cycles, ranging from 1k to 200k cycles in lab air at 25°C and 30% relative humidity
- Density was determined prior to sliding from mass and caliper measurements; mass was recorded before and after each cycle set using a Mettler Toledo scale (±0.00001 g); volume loss was calculated via density from mass loss
- Frictional force was continuously recorded by the tribometer and divided by normal force to obtain the coefficient of friction
- Steady state behavior was defined using the last 3 cycle sets (pure PTFE) or last 5 cycle sets (PTFE + 5% alumina)



Surface Energy

- Surface energy was determined using contact angle measurements with two probe liquids and analyzed using the Owens–Wendt method
- Three droplets each of distilled water and diiodomethane were placed on etched PTFE and PTFE + 5% alumina surfaces; the contact angle (θ) between each droplet and the surface was measured and averaged



- Surface energy components were calculated using the Owens–Wendt relation: $\gamma_l(1 + \cos\theta)/2 = \sqrt{(\gamma_s^d \gamma_l^d)} + \sqrt{(\gamma_s^p \gamma_l^p)}$
- Diiodomethane ($\gamma_l^p = 0$) simplifies the relation to solve the dispersive component directly: $\gamma_s^d = 50.8(1 + \cos\theta\_DIM)^2 / 4$
- The polar component was then solved using the averaged water contact angle: $\gamma_s^p = (72.8(1 + \cos\theta\_H_2O)/2 - \sqrt{(21.8\gamma_s^d)})^2 / 51.0$
- Total surface energy: $\gamma_s = \gamma_s^d + \gamma_s^p$

Sample	γ_s^d (mN/m)	γ_s^p (mN/m)	γ_s Total (mN/m)
Etched Pure PTFE	33.9	0.5	34.4
PTFE + 5% Al_2O_3	27.2	1.7	28.9
Unetched Pure PTFE	26.1	1.7	27.7
Etched PTFE + 5% Al_2O_3	24.75	7.93	32.7
Stainless Steel	32.2	12.2	44.4
Glass	27.4	42.5	69.9
Charged Glass	35.9	31.6	67.5

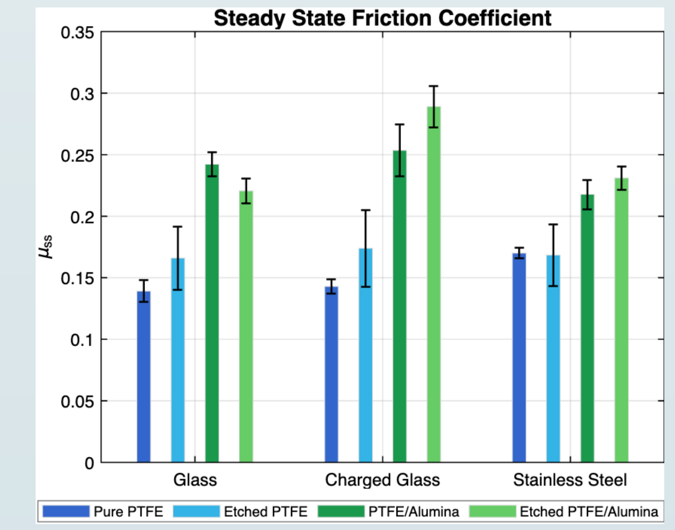
Results

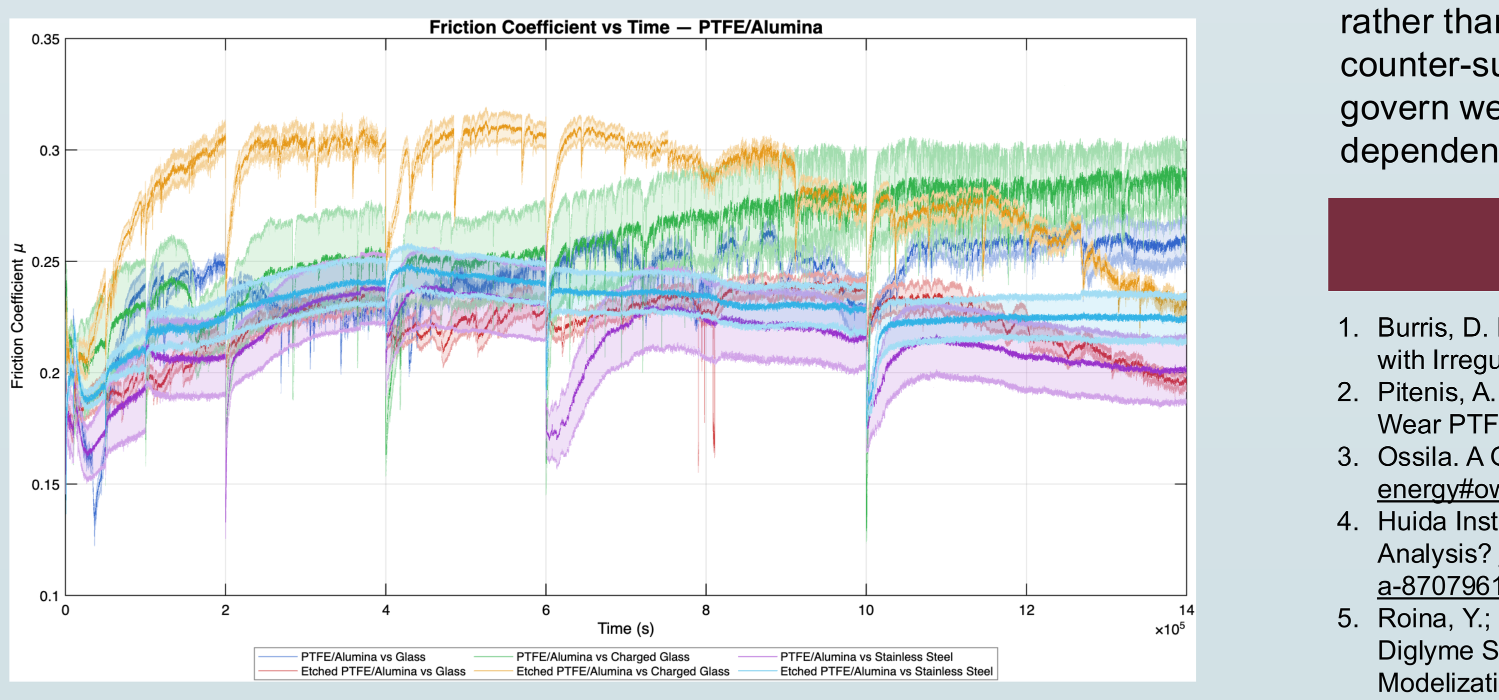
Pure PFTE Friction and Wear Data

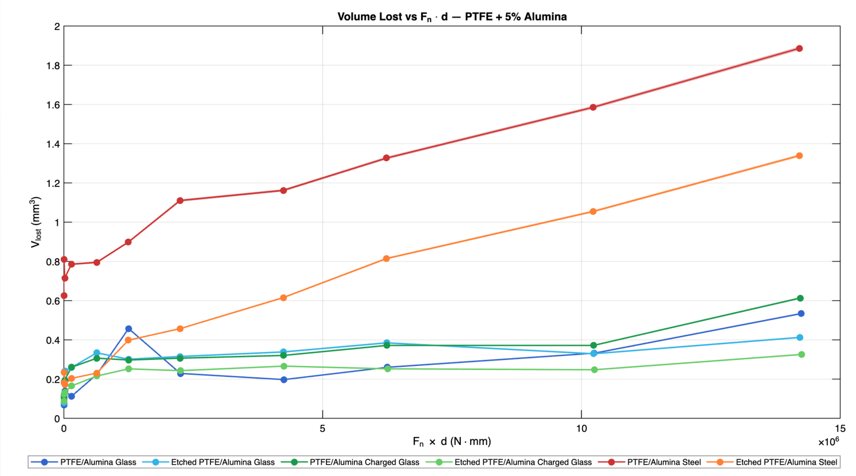
Counter Sample	Glass (Unetched)	Glass (Etched)	C-Glass (Unetched)	C-Glass(Etched)	SS (Unetched)	SS (Etched)
Average μ	0.15	0.16	0.16	0.17	0.13	0.13
Std. Deviation of μ	0.02	0.02	0.02	0.02	0.07	0.07
Steady State μ	0.14	0.17	0.14	0.17	0.17	0.17
Std. Dev. of Steady State μ	0.01	0.03	0.01	0.04	0.00	0.03
Avg. Total Wear Rate	1.54e-3	2.9e-4	1.34e-3	1.74e-4	2.03e-2	7.53e-4
Steady State Wear	2.3e-4	4.7e-5	2.8e-4	6.3e-5	7.7e-4	3.8e-4
Uncertainty of k_{ss}	5.1e-6	1.1e-6	6.3e-6	1.4e-6	1.7e-5	8.1e-6

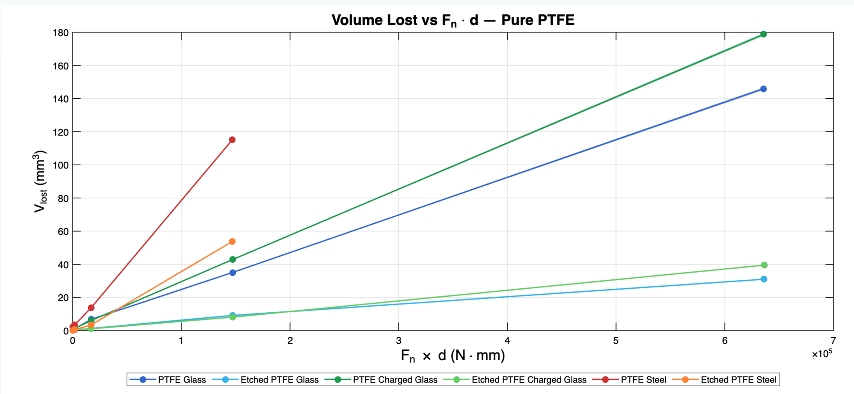
PFTE + 5% Alumina Friction and Wear Data

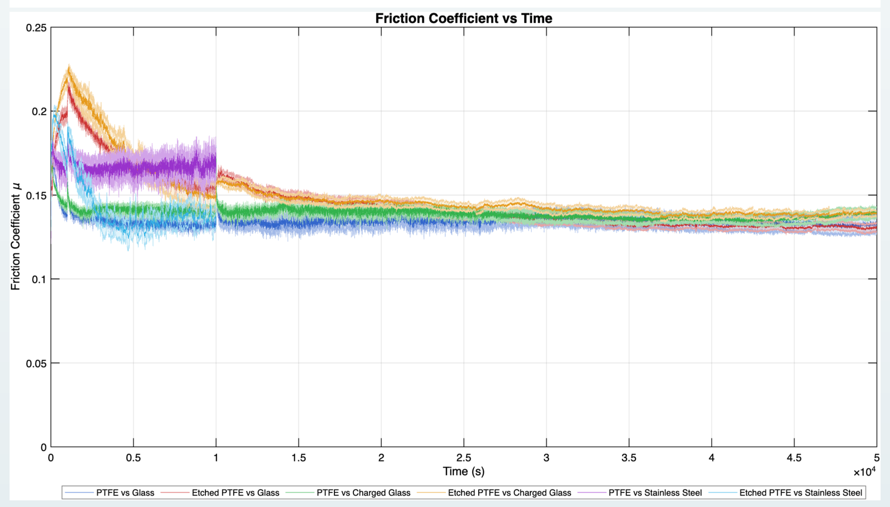
Counter Sample	Glass (Unetched)	Glass (Etched)	C-Glass (Unetched)	C-Glass (Etched)	SS (Unetched)	SS (Etched)
Average μ	0.2	0.18	0.21	0.23	0.18	0.2
Std. Deviation of μ	0.07	0.06	0.07	0.08	0.06	0.06
Steady State μ	0.24	0.22	0.25	0.29	0.22	0.23
Std. Dev. of Steady State μ	0.01	0.01	0.02	0.02	0.01	0.01
Avg. Total Wear Rate	3.5e-5	4.5e-5	5.2e-5	4.6e-5	3.3e-4	9.6e-5
Steady State Wear	2.e-8	5.9e-9	2.3e-8	5.3e-9	6.7e-8	7.3e-8
Uncertainty of k_{ss}	5.8e-10	3.5e-10	5.7e-10	3.0e-10	1.6e-9	1.7e-9











Discussion

Pure PTFE demonstrated lower steady-state friction (μ = 0.13–0.17) than PTFE/alumina (μ = 0.22–0.29) across all counter-surfaces, consistent with alumina particles disrupting the smooth PTFE transfer film.[1] Despite this, alumina addition reduced steady-state wear by approximately four orders of magnitude, confirming that tribochemical bonding of carboxylic acid end groups anchors a robust, protective transfer film.[2] Friction was primarily governed by material composition rather than counter-surface identity. Fluoroetching reduced wear across both experiments, with the effect more pronounced in the alumina composite where etching raised the polar surface energy component from 1.7 to 7.93 mN/m. This suggests increased polar character enhances chemical compatibility with the counter-surface, strengthening transfer film adhesion. For pure PTFE, etching roughly halved the wear rate across all counter-surfaces. Counter-surface energy influenced wear more than friction. Stainless steel (γ_s = 44.37 mN/m) produced the highest wear in both experiments, consistent with its low polar surface energy component. Without strong polar interactions to anchor the film, PTFE is continuously removed rather than protected, driving higher wear rates. Collectively, polar counter-surface energy, alumina reinforcement, and fluoroetching act to govern wear performance, while friction remains largely material-dependent.

References

1. Burris, D. L.; Sawyer, W. G. Improved Wear Resistance in Alumina-PTFE Nanocomposites with Irregular Shaped Nanoparticles. *Wear* 2006, *260*, 915–918.
2. Pitenis, A. A.; Harris, K. L.; Junk, C. P.; Blackman, G. S.; Sawyer, W. G.; Krick, B. A. Ultralow Wear PTFE and Alumina Composites: It is All About Tribochemistry. *Tribol. Lett.* 2015, *57*, 4.
3. Ossila. A Guide to Surface Energy. https://www.ossila.com/pages/a-guide-to-surface-energy#owrk-model (accessed March 2026).
4. Huida Instrument. Did You Know That Charged Glass Slides Play a Crucial Role in Laboratory Analysis? https://www.huidainstrument.com/info/did-you-know-that-charged-glass-slides-play-a-87079610.html (accessed March 2026).
5. Roina, Y.; Gonçalves, A.-M.; Fregnaux, M.; Auber, F.; Herlem, G. Sodium Naphthalenide Diglyme Solution for Etching PTFE, Characterizations and Molecular Modelization. *ChemistrySelect* 2022, *7*, e202200153.

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