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ANALYSIS OF GEOMETRIC PARAMETERS AND EXTERNAL LOAD ON THE FRICTION COEFFICIENT IN ADHESIVE CONTACTS

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Abstract. The friction coefficient in adhesion contacts depends on multiple factors, including material properties, external load and contact geometry. Understanding the role of these parameters is essential for optimizing tribological performance in various applications, including elastomeric seals, biomedical devices, and soft robotic interfaces. This study investigates the effect of geometrical contact profile $f(r) = c_n r^n$ in combination with the external load and material parameters on the friction coefficient. Theoretical modeling is conducted using principles of adhesive contact mechanics, while MATLAB-based numerical simulations are utilized to visualize the effects of the geometric and loading parameters. The results suggest that controlling the parameters can be an effective strategy for tuning friction in adhesion contacts, providing practical insights for the design of soft interface systems.

Keywords: Adhesion, Friction coefficient, Surface geometry, Indenter, Elastomer, Contact area, External load, Material parameters.

Adgezion kontaktlarda ishqalanish koeffitsiyentiga geometrik parametrlar hamda tashqi yuk ta’sirining tahlili

Annotatsiya. Adgezion kontaktlarda ishqalanish koeffitsiyenti bir qator omillarga, jumladan material xossalari, tashqi yuk hamda kontakt geometriyasiga bog‘liq. Ushbu parametrlarning rolini chuqur anglash turli amaliy sohalarda, xususan elastomer muhrlar, biotibbiy qurilmalar va yumshoq robototexnika interfeyslarida tribologik samaradorlikni optimallashtirish uchun muhim ahamiyat kasb etadi. Mazkur tadqiqotda geometrik kontakt profili $f(r) = c_n r^n$ ning tashqi yuk va material parametrlar bilan birgalikdagi ta’siri ishqalanish koeffitsiyentiga nisbatan o‘rganildi. Nazariy modellashtirish adgezion kontakt mexanikasi tamoyillari asosida amalga oshirildi, MATLAB dasturiy muhiti yordamida bajarilgan sonli simulyatsiyalar esa geometrik va yuk parametrlarining ta’sirini vizual tahlil qilish imkonini berdi. Olingan natijalar parametrlarni boshqarish adgezion kontaktlarda ishqalanishni moslashtirishning samarali strategiyasi bo‘lishi mumkinligini ko‘rsatdi hamda yumshoq interfeys tizimlarini loyihalash uchun amaliy tavsiyalarni taqdim etdi.

Kalit so‘zlar: adgeziya, ishqalanish koeffitsiyenti, sirt geometriyasi, indentor, elastomer, kontakt maydoni, tashqi yuk, material parametrlari.

Анализ влияния геометрических параметров и внешней нагрузки на коэффициент трения в адгезионных контактах

Аннотация. Коэффициент трения в адгезионных контактах зависит от ряда факторов, включая свойства

материала, внешнюю нагрузку и геометрию контакта. Понимание роли этих параметров имеет существенное значение для оптимизации трибологических характеристик в различных областях применения, в частности в эластомерных уплотнениях, биомедицинских устройствах и интерфейсах мягкой робототехники. В настоящем исследовании изучается влияние геометрического профиля контакта $f(r) = c_n r^n$ в сочетании с внешней нагрузкой и параметрами материала на коэффициент трения. Теоретическое моделирование выполнено на основе принципов механики адгезионного контакта, а численные моделирования, реализованные в среде MATLAB, использованы для визуализации влияния геометрических и нагрузочных параметров. Полученные результаты показывают, что управление указанными параметрами может служить эффективной стратегией регулирования трения в адгезионных контактах и предоставляет практические рекомендации для проектирования систем с мягкими интерфейсами.

Ключевые слова: Адгезия, Коэффициент трения, Геометрия поверхности, Индентор, Эластомер, Площадь контакта, Внешняя нагрузка, Параметры материала.

1.Introduction. Friction, defined as resistance encountered when two surfaces slide or attempt to slide over each other, is a fundamental phenomenon in various mechanical and tribological systems. The analysis of the friction coefficient in adhesive contacts is of significant importance in various industrial and scientific research areas. In nature, large animals employ adhesion mechanisms that primarily function through Van der Waals interactions [1]. Adhesion between solid bodies is not commonly observed in practice, mainly because natural solid surfaces are inherently rough. Due to this surface roughness, the actual area where adhesion forces come into effect is considerably smaller than the nominal contact area perceived externally. Consequently, the influence of adhesive forces becomes limited and often negligible.

Adhesion can be controlled by modifying either the contact area or the contact strength. Both are dependent on shear force [2], as pushing the adhesive pad away from the body creates an unstable contact and, therefore, a decreasing contact area, whereas pulling the pad toward the body increases the contact area. Moreover, modifying the contact area and strength plays a crucial role in regulating adhesion. As the contact area increases, adhesive forces become stronger due to increased surface interactions between the contacting bodies. However, when the contact becomes unstable due to surface roughness or misalignment, the real contact area decreases, thereby reducing the adhesive forces. Therefore, effective control of adhesion requires a thorough understanding of the relationship between contact area and contact strength. Therefore, effective adhesion control depends on understanding the relationship between the contact area and strength. Similar principles are explored in the work by Voyer et al., where laser-textured molds were used to manipulate surface contact behavior in elastomers [3].

In macroscopic contacts, the friction force is often roughly proportional to the normal force and, thus, the Amontons's law $F_x = \mu F_N$ is valid. On the microscale, on the contrary, many studies show the proportionality of the frictional force to the contact area *A*, i.e, $F_N = \tau A$, where τ is the (approximately constant) tangensial stress in the contact area necessary to shear the interface. In source [4], the dependence of the friction coefficient on indentation depth in adhesive contacts between an elastomeric layer and steel indenters was analyzed using both experimental and simulation methods. Drawing on previous findings, this work provides a theoretical analysis of friction in adhesive contacts, examining how variations in the geometric contact profile and applied load influence the friction coefficient.

2. Materials and Methods. In situations where adhesive interactions are the main source of friction, the frictional force can be estimated using the following [5-7].

$$F_x = \tau_0 A_r \quad (1)$$

where A_r is real contact area and τ_0 are the tangentional stresses that are necessary to break the adhesive bonds and initiate the sliding mode. Due to the inherent surface roughness of solid materials, the real contact area (A_r) in typical engineering interfaces is considerably smaller than the nominal contact area (A), which influences the accuracy of contact-based measurements and friction modeling. According to Equation (1), the critical shear stress (τ_0), which is determined by the adhesive characteristics of the contacting surfaces, remains constant, while the real contact area (A_r) increases linearly with the applied normal load [8].

$$A_r = \alpha F_N \tag{2}$$

as a result, the well-known Amonton's friction law emerges:

$$F_x = \mu F_N \tag{3}$$

where a constant friction coefficient ($\mu = \alpha\tau_0$) is introduced. In many cases, especially when dealing with dry friction between solid materials that lack strong adhesive interactions, the frictional force can be reasonably well approximated using Amontons's law (3)**.** In highly adhesive contacts, where the real contact area (A_r) nearly equals the nominal area (A), expression (2) no longer holds true due to the near-complete contact between surfaces. Consequently, Amontons's law (3) does not apply, and the friction behavior must instead be described using alternative formulations, as discussed in [5,9].

$$F_x = \tau_0 A. \tag{4}$$

where (A) is the nominal contact area, which coincides with the real contact area, (A_r). Let us consider the general case of an axially symmetric indenter, where the indenter profile is specified by a power function

$$f(r) = c_n r^n, \tag{5}$$

where r is the radial coordinate. In particular, the friction law (4) is observed in contacts with strong macroscopical adhesion, e.g., when a hard indenter is pressed into a soft elastomer. The friction coefficient μ is defined in a standard way

$$\mu = \frac{F_x}{F_N} \tag{6}$$

In adhesive contacts, the contact radius a is determined based on the applied normal force F_N and material properties. The indentation depth d and friction coefficient μ are given by [4]:

$$d = \left(\frac{F_N(1-\nu^2)(1+n)(c_n k_n)^{\frac{1}{n}}}{2nE^*}\right)^{\frac{n}{n+1}};\ a = \left(\frac{d}{c_n k_n}\right)^{\frac{1}{n}};\ A = \pi a^2; \tag{7}$$

where k_n is a constant, $E^* = \frac{E}{1-\nu^2}$ is the effective elastic modulus of the half-space, and ν is its Poisson's ratio. Here, n is profile exponent, c_n is profile coefficient, τ_0 is the shear stress, A is contact area, and a is the contact radius.

In the case where the friction force is proportional to the contact area $F_x = \tau_0 A$ (2), the friction coefficient μ is determined by equation (6), which leads to the dependence of the friction coefficient μ on the normal force F_N in the form [4,10]

$$\mu(F_N) = \pi\tau_0 \left(\frac{(n+1)}{2nE^* c_n k_n}\right)^{\frac{2}{n+1}} \times \frac{1}{(F_N)^{\frac{n-1}{n+1}}}. \tag{8}$$

3. Results

The experiments indicate that tangential stresses depend on pressure according to the formula [10]:

$$\tau = \tau_0 + \alpha P^\gamma, \tag{9}$$

where τ_0 is the constant shear steress, and α, γ are empirical constants which can be found from experiment. Substituting equation (9) into equation (8), we obtain the following expression [10]:

$$\mu = \tau_0 \left(\frac{A}{F_N}\right) + \alpha \left(\frac{A}{F_N}\right)^{1-\gamma}. \tag{10}$$

The analysis of equation (10) is examined below based on several graphs that illustrate the influence of model parameters on the friction coefficient. Figure1 presents a 3D surface plot illustrating the dependence of the coefficient of friction μ on both the profile coefficient (c_n) and the applied normal force (F_N). The graph shows that as (c_n) increases, (μ) decreases in a nonlinear manner. This behavior can be attributed to surface smoothing, which reduces the effective area of

adhesion. Simultaneously, an increase in (F_N) also leads to a reduction in (μ), especially in the low-force regime (e.g., 1-20N), where adhesion dominates the contact mechanics and results in higher (μ) values. As the load increases, contact mechanics shift towards elastic deformation, reducing the relative contribution of adhesion. Consequently, (μ) decreases and the surface trend flattens. Overall, the highest friction values are observed under low (c_n) and low applied loads(F_N)**.**

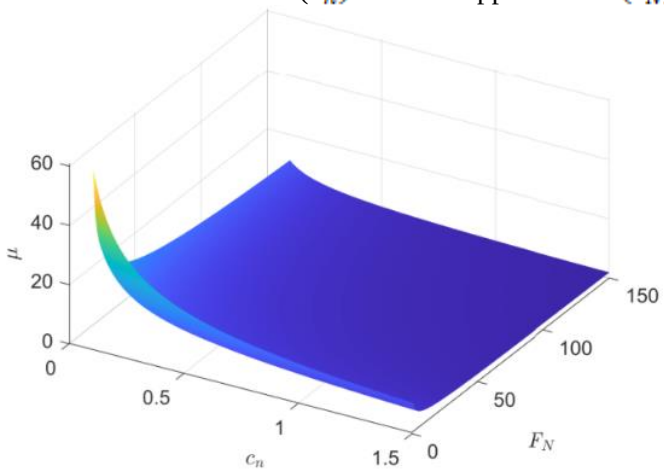


Figure 1 – Dependence of the friction coefficient μ on normal force F_N and geometrical profile characteristics.

Figure 2a provides 2D cross-sectional views of the μ - c_n relationship at selected constant values of (F_N) (e.g., 50,100, and 150N). These plots reveal that (μ) decreases nonlinearly with increasing (c_n), and this effect is especially pronounced at lower normal forces. For instance, at $F_N = 50N$, μ drops from approximately 15 when $c_n = 0.2$ to around 7.5 when $c_n = 0.6$. At $F_N = 100N$, μ is around 5, and at $F_N = 150N$, it becomes even lower. These changes clearly demonstrate the model's sensitivity to the profile coefficient and adhesion. Furthemore, the sensitivity diminishes as the normal load increases.

Figure 2b shows how (μ) varies with (F_N) for different values of the profile coefficient c_n(0.2,0.5,1,1.5). It is evident that (μ) decreases with increasing (F_N), due to the transition from adhesion-dominated behavior to elastic deformation. At low loads, (c_n) significantly influences (μ), while at higher loads, the differences between the curves diminish. This suggests that at large normal force, the influence of profile coefficient on friction becomes less significant.

In summary, all three figures highlight that (μ) depends nonlinearly on both (c_n) and (F_N). At low normal loads, (μ) is high due to strong adhesion effects.As the load increases, the role of adhesion weakens and elastic deformation dominates, leading to a decrease in (μ). This behavior confirms the model's ability to realistically capture contact mechanics under contact geometry and loading conditions.

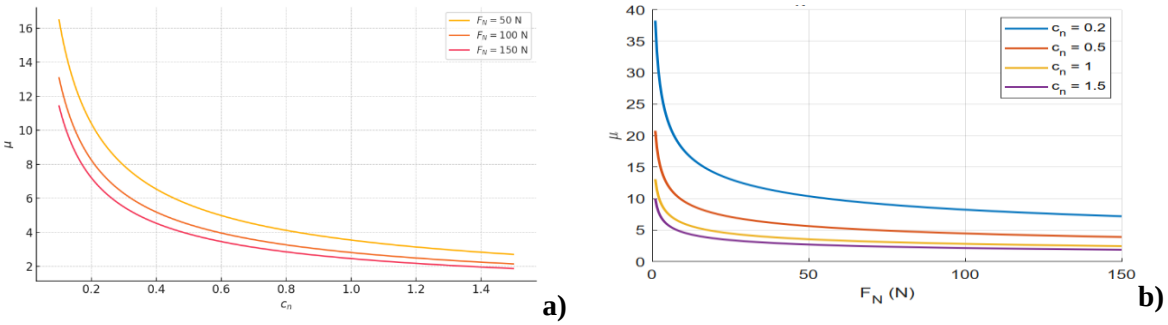


Figure2 – Detailed analysis of the friction coefficient (μ) with respect to model parameters: (a) Dependence of μ on profile (c_n) under constant normal forces (F_N); (b) Dependence of (μ) on normal force (F_N) for different profile coefficient values (c_n).

In the following analysis, additional graphs were examined to further explore the effects of different parameters on the friction coefficient. The 3D plot presented in Figure 3 demonstrates the combined effect of the profile exponent (*n)* and normal force (F_N) on the friction coefficient (μ). As can be seen, the surface exhibits a nonlinear behavior, where (μ) increases significantly with increasing (*n),* especially at lower values of (F_N). Conversely, an increase in (F_N) leads to a consistent reduction in (μ) across all values of (*n*). This behavior is attributed to the expansion of real contact area under higher loads, which in turn reduces the apparent friction coefficient. The surface also indicates that the sensitivity of (μ) to changes in (*n*) is more pronounced when the normal force is low.

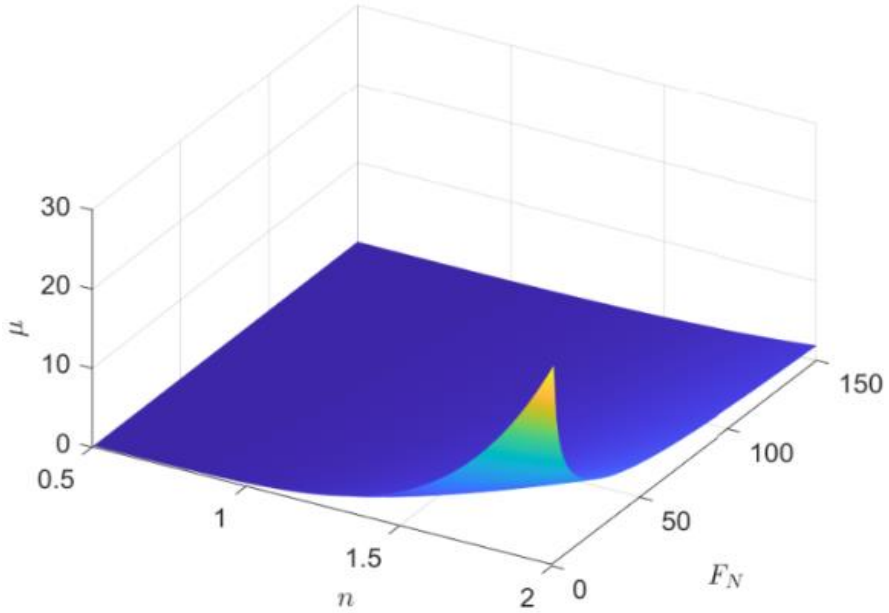
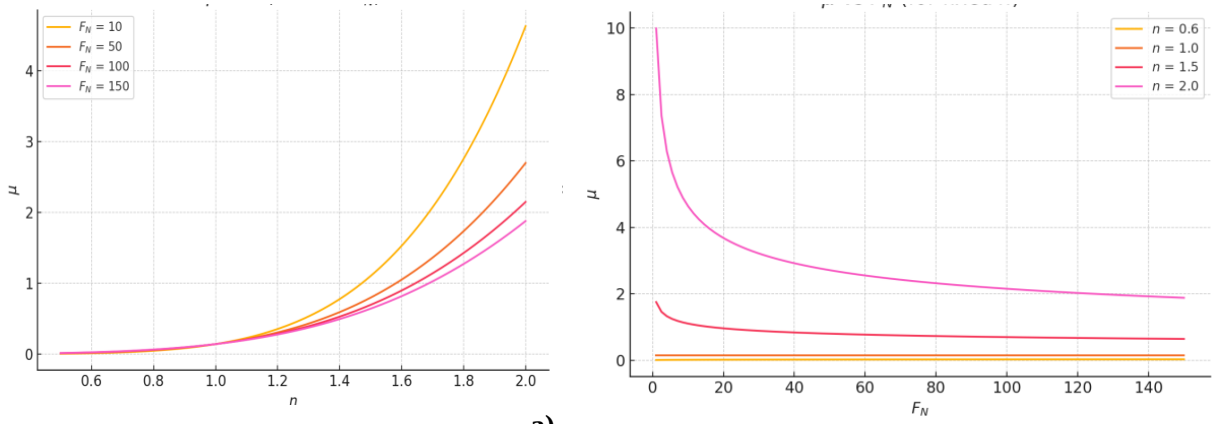


Figure 3 - Variation of the friction coefficient (μ) with respect to profile exponent (*n)* and normal force (F_N).

In Figure 4a, 2D plots of the friction coefficient (μ) as a function of the profile exponent (*n*), for several fixed values of the normal force (F_N). It is observed that for all values of (F_N), (μ) increases nonlinearly with increasing (*n*). However, the rate of increase is steeper at lower values (F_N). For example, when $F_N = 10$, the increase in (μ) with respect to (*n*) is much sharper compared to when $F_N = 150$. This indicates that the influence of material deformation behavior (represented by (*n*)) becomes more dominant when the contact pressure is low.

In figure 4b, the relationship between the normal force (F_N) and the friction coefficient (μ) is analyzed for fixed values of the parameter (*n*). The results confirm that (μ) decreases with increasing (F_N), regardless of the value of (*n*). This inverse relationship highlights the role of increased contact area under load, which reduces the localized stress and thus the friction response. Moreover, higher values of (*n*) results in significantly greater values of (μ), particularly in the lower range of (F_N). The graph illustrates that for larger (*n*), the friction coefficient starts at a much higher level and declines rapidly with increasing force, then gradually stabilizes.



a) **b)**

Figure 4 - 2D plots illustrating the influence of profile exponent (*n*) and normal force (F_N) on the friction coefficient (μ): (a) Variation of (μ) with respect to (*n*) for fixed (F_N) values. (b) Variation of $(\mu)$with respect to (F_N) for fixed (*n*) values.

4. Conclusions. In this study, the role of various model parameters affecting the frictional behavior of elastomeric materials under applied pressure was theoretically investigated. The results reveal that (μ) exhibits a strong nonlinear dependence on these parameters. At low normal forces (F_N), the coefficient of friction (μ) is significantly higher due to the dominance of adhesive interactions. As the load increases, the behavior transitions toward elastic deformation, diminishing the influence of adhesion and causing a reduction in (μ). An increase in the profile exponent (*n*) leads to a pronounced rise in (μ), especially at low(F_N), indicating that the material's deformation behavior plays a dominant role in determining the friction response. Similarly, increasing the profile coefficient (c_n)results in smoother surfaces, which reduce the real contact area associated with adhesion, thereby lowering the overall friction coefficient. Overall, the modeling approach and graphical analysis clearly demonstrate the sensitivity of frictional behavior to variations in loading conditions and surface geometry. These findings provide valuable insights for designing and optimizing tribological systems where elastomeric materials are used under varying mechanical and surface conditions.

References

1. Gao, H.; Wang, X.; Yao, H.; Gorb, S.; Arzt, E. Mechanics of hierarchical adhesion structures of geckos. Mech. Mater. 2005, 37,275–285.
2. Waters, J.F.; Guduru, P.R. Mode-mixity-dependent adhesive contact of a sphere on a plane surface. Proc. R. Soc. A 2010, 466, 1303–1325.
3. Voyer J., Ausserer F., Klien S., Velkavrh I., and Diem A. "Reduction of the Adhesive Friction of Elastomers through Laser Texturing of Injection Molds," Lubricants 2017.
4. Lyashenko, I.A.; Pham, T.H.; Popov, V.L. Effect of Indentation Depth on Friction Coefficient in Adhesive Contacts: Experiment and Simulation. Biomimetics 2024, 9, 52.
5. Bowden, F.P.; Tabor, D. The Friction and Lubrication of Solids; Oxford University Press: New York, NY, USA, 1950; p. 337.
6. Yoshizava, H.; Chen, Y.-L.; Israelachvili, J. Fundamental mechanisms of interfacial friction. 1. Relation between adhesion and friction. J. Phys. Chem. 1993, 97, 4128–4140.
7. Ozaki, S.; Mieda, K.; Matsuura, T.; Maegawa, S. Simple Prediction Method for Rubber Adhesive Friction by the Combining Friction Test and FE Analysis. Lubricants 2018, 6, 38.
8. Liang, X.M.; Xing, Y.Z.; Li, L.T.; Yuan, W.K.; Wang, G.F. An experimental study on the relation between friction force and real contact area. Sci. Rep. 2021, 11, 20366.
9. Bowden, F.P.; Tabor, D. The Friction and Lubrication of Solids; Oxford University Press: New York, NY, USA, 1950; p. 337.
10. Lyashenko, I.A.; Pham, T.H.; Popov, V.L. Controlling the Friction Coefficient and Adhesive Properties of a Contact by Varying the Indenter Geometry. Processes 2024, 12, 1209.

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