The Heterogeneity, Adsorption, Friction, and Materials-Energy Balance: a Preview

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Abstract. The Synchronization of bio-inspired adsorption carried scientific innovation of engineering applications at the interface of material-energy balance in presence of heterogeneous third bodies. Friction is indispensable in atomic-, nano-, micro-, macro-, and large domains and theoretically null in an ultra-vacuum. Lubrication for preventing biomacromolecule adsorption at the cartilage-cartilage interface is a mechanical diffusion mechanism in replicating tribology. A mechanical stick-slip zone to ultra-low friction at articulating cartilage in boundary lubrication is fundamentally incorporated for a synergistic impact on society.

Keywords: Mechanical interlocking, Adhesion, Energy balance, Carbon, Bio-materials.

1 Introduction

Adhesion, lubrication, and friction create an expression of tribology for a synergistic materials-energy balance. Covid#19 pandemic outbreak is an environmental load of anthropogenic activities for modulation of carbon footprints emission from transport, manufacturing, change of land use, and energy sectors. The economy is a function of carbon due to bioavailability, biocompatibility, functionalities, and nature consciousness. Carbon dioxide capture and storage have been promoted for the transformation of the energy sector in the 21st century assumed to be a scientific route for the reduction of atmospheric carbon. European countries are changing towards clean energy borrowed from the low-grade thermal energy of the biosphere. Friction at the tribological interface of mechanical machinery contributes a significant portion of fuel energy consumption for safeguarding academic inertia towards green lubricants or green technology. Nanotechnology-based on carbon nanomaterials, nanocellulose, and carbon dots, cytotoxicity, and biofunctionalization may be viable for resolving underlying adhesion mechanisms with bio-interface. Friction at sliding mechanical surfaces is a strong function of environmental third bodies in designing functional surfaces. Adsorption of a few layers of molecular coat over the mechanical surface, interface, and interphases enhance lubricity, durability, economy, and reliability of tribological contacts.

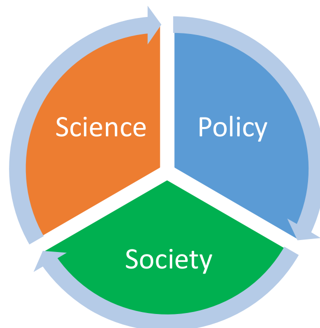

Fig. 1. The socioeconomic empowerment at Science-Policy-Society interface for advancement of scientific innovation and promotion of decent work in concurrence with global indicators, sustainability, green tribology, and synergy of planet health.

Green technology, sustainable communities, strategies for the promotion of clean energy, and the action-reaction hypothesis altogether contribute to academic cum scientific innovations. The Rio Earth Summit in 1992 or Rio Convention, adoption of the United Nations Framework on Climate Change (UNFCCC) entered into force on March 21, 1994, agenda of the Conference of Parties (COP) to review convention implementation, and Kyoto Protocol had paved milestones to stabilize greenhouse gases (GHGs) from anthropogenic interference [1]. The Paris Agreement is a political treaty to mitigate global warming, well below 2 and preferable to 1.5 degrees Celsius, adopted by 196 political Nations on December 12, 2015, at COP in Paris and entered into force on November 4, 2016, for the achievement of the target [2]. The scientific, technical, and socioeconomic assessment of global warming of 1.50C and comparison of global warming above pre-industrial levels is reported by the IPCC special report for fruitful health of the planet [3]. The capture and utilization of environmental carbon dioxide evolved from anthropogenic or industrial inputs by scientific methods may reduce the cost of products during the 21^{st} century however a little influence on global warming by capturing or use of carbon molecules [4]. Tribological surface dissipates approximately one-third of fuel energy expenditure for reduction and wears of mechanical machinery in terms of global GDP, CO2 emissions, and advancement of green technology [5]. The contribution of transport, energy, industry, and residential to socioeconomic frontier is viable (Fig. 1) for a materials-energy balance as per existing global parameters.

2 Origin of tribology

Nature has evolved hydrophobic and oleophobic surfaces for water repellency, self-cleaning mechanism, material energy balance, and “*Biomimicry*” biological interface for designing functional materials. Adsorption, lubrication, friction, and wear from single asperity to large fields is termed tribology for rationalization of interfacial environment. Friction force at the tribological interface is dependent on normal load, sliding speed, the real area of contact, heterogeneity, and environmental factors. Bio-inspired membranes replicate biological soft matter for amphiphilic performance at bio-tribology as per the requirement in diffusion, surface tension generation, biomedical implant grafting, and anti-friction properties. Supramolecular interaction of water molecules, ice with a hydrophobic surface, biological lubricants, and oleophobic biological interface provide a relatively low coefficient of friction than a bio-inspired interface. The importance of friction is omnipresent in engineering applications for the optimization of energy dissipation at TRIBO interface in a molecular domain to macrodomain for academic usefulness, rendering, and irreversibility. The amalgamation of nanoparticles in a limited dose with lubricant reduces a little friction due to heterogeneity at the sliding mechanical interface. The macroscopic friction model widely accepted in engineering applications up to nanotribology is Amontons' law of friction [6-7]. The ratio of friction force to normal load is the coefficient of friction ($\mu = F/N$) and according to Amontons' law coefficient of friction is independent of normal load/the apparent area of contact. The shear force on the mechanical substrate responsible for impending motion is static friction force, under motion is kinetic friction force, and kinetic friction force is less than static friction force. The coefficient of friction is expressed in concurrence of Amantons' law as coefficient of friction independence on normal load or apparent area of contact shall not violate dependence on sliding speed, real area of contact, and environmental factors.

$$\mu = \mu_S - (\mu_S - \mu_K)f^* \quad \text{(i)}$$

Where, 'μ' is the local coefficient of friction, subscript 'K' for 'Kinetic', 'S' representing 'Static', and $0 \le f^* \le 1$ is a fraction incorporates real area of contact, sliding speed, heterogeneous third bodies, and environmental factors. Adhesion at bio-inspired interface is evolved by mechanical interlocking, diffusion, adsorption, and electrostatic interaction for regulation of frictional stress as a function of state variables. The adhesion of soft matter in tribological contact is depicted by Hertzian case for prediction of reduced elastic modulus. Hertzian theory is based on classical mechanics and useful for analytical solution of elastohydrodyanmic problems. Hertz contact theory is based on assumptions included in brief (i) Infinite surface (ii) Homogeneous materials (iii) Parabolic pressure profile (iv) Small strains.

$$\frac{1}{E^*} = \frac{(1-\nu_1{}^2)}{E_1} + \frac{(1-\nu_2{}^2)}{E_2} \quad \text{(ii)}$$

Materials research for designing surface, interface, and interphases has changed friction in dynamic conditions. Bio-inspired tribology is an emerging interdisciplinary field of physiochemical, technology, and scientific innovation for rationalization of energy dissipation losses. Bio-tribology at interface of biomedical and mechanical engineering have been preferred by mechanical fraternity for achievement of visible academic performance indicators.

3 Stick-slip friction

Stick-slip friction at sliding substrate on slipping substrate is a dynamic cycle "*Boon*" or "*Bane*" for human performance indicators. Regulation of stick-slip friction is ubiquitous in daily life for doing useful mechanical work by human energetics, indoor walk, running, aerobics, local traveling at sliding foot on footwear tribological surface. Classical laws of friction state that friction force is independent of the apparent area of contact whereas the real area of contact or surface science is valuable for assessment of palpable friction force over irregular surfaces, human skin, and soft matter [8-9]. Lean hydration lubrication, reducing surface tension, aging, degradation of a biological membrane, environmental factors, lesser mechanical efficiency, and work-life imbalance promotes stick-slip friction in bio-tribology. The stick-slip friction at articular cartilage is a transformation of bio-interface due to collagen/hyaluronic acid/glycosaminoglycans/cartilage digestion, increase of surface roughness, and morphological change [10]. Transmission of shear force by mechanical interlocking of interfacial asperities, the real area of contact, roughness, and surface science are primary parameters in the propagation of perceptible stick-slip friction for severe energy dissipation.

The driving force applied on the stick-slip interface generates the viscoelastic effect in an environment for perceptible music useful for emotional resilience when the bow moves over the strings of the Violin [11]. The stick-slip effect in a musical system is created by elasticity, static friction, kinetic friction, relative sliding velocity of the mechanical substrates, damping effect, and human energetics for palpable sound by the large amplitude of vibrations in a conscious environment [12]. The seismic stick-slip friction for basal sliding at the base of an alpine glacier changes static friction to kinetic friction for a significant amount of ice shearing at the heterogeneous juncture in a large field [13]. Stick-slip friction is a transformation of the externally applied force into inertia, viscous damping, Coulomb damping, and spring potential in the achievement of innovative goals as depicted (Fig. 2) for mathematical modeling.

Fig. 2. Elementary expression of mass, damper, spring dynamic system subject to harmonic excitation for stick-slip friction rheology in bio-inspired tribology (a) Inertia force is a function of mass and acceleration (b) Viscous damping for environmental sound generation (c) Coulomb damping for frictional energy loss (b) Spring carried an expression of elasticity (d) The driving force is termed harmonic excitation

4 Adsorption

Adsorption is a phenomenon of molecules transfer by physical or biochemical actions over surface, interphase, and interphases. A greenhouse gas CO_2 adsorption by photosynthesis is a material energy balance for the evolution of the most abundant hydrophilic cellulose biopolymer. A few layers of melamine formaldehyde thermosetting resin adsorption or coating over cellulose fiber composites lamina or natural wood provide durability, mechanical resistance, transparency, thermal stability, flame retardant, moisture resistance, surface smoothness, and protection from environmental degradation in the urban city's household fitting/fixtures [14]. Natural fiber composites coated by thermoplastic/thermoset adsorbents are preferred in the leading car manufacturing industries for the advancement of green technology and the promotion of scientific innovation from an economic perspective [15]. Biocompatibility, biodegradability, and mechanical properties are the indicators in the selection/designing/fabrication of biomaterials.

Lactic acid, glycolic acid, and citric acid-based crosslinking polymers are preferred in a biomechanical domain for manufacturing biomedical implants due to bio-adsorption by "*Hydrolysis*" or "*Hydrophilicity*". Graphene-based nanoparticle adsorption over the biological membrane is viable in biomedical applications for re-searching at nanotribology interface, cytotoxicity, ultra-functionalization in the presence of hydroxyl terminals for foreign charged particles, and lean antifriction properties for tribological surface conversely polytetrafluoroethylene is a theoretically inert molecule useful for non-toxic and non-stick coatings [16]. Adsorption of carbon particles, particulate matters, and residual unwanted anthropogenic load by mechanical driven air purifier across an anisotropic fibrous panel of air purifier for work-life balance is a bio-inspired mechanism in aligned with sustainability. Natural oils or petroleum-based cosmetics are skin adsorbents for environmental protection used as skin conditioners, softeners, moisture carriers, and bio-tribological thickeners.

5 Biomaterials

The biocompatibility, bioavailability, and mechanochemical properties are preferred in designing of biomaterials intended to adhere with biological systems. Biomaterials are ceramics, synthetic polymers, and natural biopolymers for synchronization with biological interface. The textured *Glycine max (L.) Merr.* is a palpable energy biomaterial food for securing sustainable pattern of consumption, fuel-oxidation, and providing a work-life balance in modulation of cultural food by people involved in economic activities. The texturing of east Asia based legume ease bio-adsorption of macromolecules in presence of water molecules for a rational release of chemical energy into mechanical work. SARS-CoV-2 pandemic is an environmental load of carbon particles, air borne syndrome, and inverse influence over fuel oxidation in terms of a synergistic general health. The biomaterials included in brief are functional materials in providing bio-adsorption efficacy at biological systems.

Material research in the first half of 20th century on glycolic acid and other alpha hydroxyl acid-based polymer synthesis was abandoned due to lean durability for industrial uses. Polymer scientists working for design and manufacturing of biomedical devices have achieved performance for last five decades of poly(lactides) and poly(glycolides) in orthopedics due to biodegradability or bioabsorbable interface [17]. The integrity of biomaterials, drug delivery, and tissue engineering have been evolving biomedical application for providing synthetic environment or information in designing of functional surfaces for cell adhesion [18]. The mechanochemical properties of poly(L-lactide)–poly(ε-caprolactone) multiblock copolymers in the formation of high molecular weight (240-490 kDa), elastic moduli (42.6-95.1 MPa), tensile strength (24.9-36.4 MPa), and ~500 percent elongation are useful for preventing adhesion at tribological sites [19]. The composite of the biodegradable elastomer poly(1,8-octanediol-citrate) and the bioceramic hydroxyapatite or POC-HA may be feasible for fabricating tissue fixation devices such as pins, plates, and screws than poly(L-lactide) due to faster degradation rate [20]. The relevance of bio adsorption for designing and manufacturing biomaterials have been pacing for the last few decades in biomedical applications.

6 Metal working

Tribology in metal working, sliding, and twisting interface reduces energy expenditure for qualitative product forming. Oil in water emulsion, nanotribology, and diamond like carbon coat are indicators for advancement of tribological research. Mechanical interlocking of asperities at sticking/sliding contacts is a mechanism for significant energy loss in dry contacts and touch friction coefficient to “Unity”. Material properties, surface science, operating conditions, and selection of lubricants provide a material-energy balance for performance parameters. Hydrodynamic lubrication, mixed lubrication, and boundary lubrication cumulatively explore the mechanics of mechanical contact in metal forming processes. The friction models extended for metal working tribological surface in dry conditions have been proposed by researchers due to shearing of asperities contacts or deviation of classical friction laws whereas the presence of lubricants transform the nature of sliding interface in terms of energy losses as a function of heterogeneous environment [21]. The thermal heating of deforming metals due to the involvement of energy expenditure for plasticity change the rheology of friction, adhesion, and wear conditions while elastic deformation account is negligible.

Hydrostatic extrusion process deforms metals under hydrostatic pressure in formation of lubricant film by *in situ* pumping or assuming hydrodynamic action. Upper bound theorem of plasticity is one of the conventional methods for prediction of energy involved for rigid plastic materials [22]. Extrusion of hard Tungsten alloy materials viability is modeled using non-Newtonian lubricant in work zone due to elevated shear strains in assumption of Newtonian attributes of inlet zone as complete bifurcation at boundary [23]. Tresca friction law provide better estimate for assessment of frictional behavior of commercially pure aluminum as a function of billet material strength, environmental factors, and operating parameters [24]. The global political trend for mitigation of working environment as well as ecology resilience has driven academic fraternity for development of new environmentally benign lubricants for metal forming viz. cold forging, hot forging, sheet forming, punching, and blanking [25]. The friction at tool and workpiece in metal forming influences the material flow, surface quality of product, and tool life as a strong function of real area of contact in providing sticking and sliding dry tribological interface [26]. The influence of real area of contact is nullified by the presence of third bodies lubricant layer for change of environmental as per the requirement in energy budget, economy, and green tribology. The influence of die shape, spinning effect, and nanotribology or boundary lubrication for molecular coat over die may evolve academic perspective for researching at tribological domain with reference to power budget or energy savings.

7 Biomimicry

Nature has evolved of surface, interface, and interphases for protection of diversity of biology. Adhesion, lubrication, and wear at tribological contact is influenced not only by interfacial environment but also free surface energy or water repellency. The super-hydrophobicity is defined at which water contact angle is more than 150 degrees for preventing environmental adsorption. Lotus leave interface are the most water repellent natural surface for explaining self-cleaning mechanism of nature termed “Lotus effect” for biomimicry superhydrophobic surface useful in engineering applications. The free surface energy of Teflon and diamond like carbon are lesser than free surface energy of water. Minimization of surface energy or surface tension by scientific route is an optimum channel for producing tribological performance from nature inspired materials. Superficial zone membrane of articular cartilage is amphiphilic and provide low friction due to biomechanical exudation. Biomimicry membrane in designing amphiphilic polymers is preferred in bio-tribology applications such as grafting of artificial membrane over implants, contact lenses, and residual biomedical applications.

Plant based CO_2 adsorption transform environment carbon into macromolecules such as cellulose, hemicellulose, and lignin for synthesis of natural composites. Cellulose is an abundant hydrophilic biopolymer found over mother planet useful for promotion of green technology. Textile industries are conventionally manufacturing hydrophilic bio-inspired surfaces for providing resistance against hydration lubrication during human energetics. Paper industries are producing hydrophilic papers useful for manifold applications. Tribology of hydrophilic surface, interface, and interphases are invincible in daily life as per the requirement of socioeconomic indicators. Sea water fishes skins are biologically oleophobic for providing low friction coefficient, regulation of thrust power, and protection against predators. Biomimicry of oleophobic surface may be viable for reducing tactile friction, designing touch pad materials of electronic gadgets, and manufacturing of oleophobic hydrogels. The nature inspired surfaces based on hydrophobicity, amphiphilicity, hydrophilicity, and oleophilicity transform surface energy or surface tension for designing TRIBO functional interface useful for human performance indicators.

8 Case study

The natural fiber polymer composites lamina is viable for advancement of green technology and promotion of socio-economic indicators. The physiochemical, thermal resistance, abrasion resistance, durability, and tribological performance is enhanced by a few layers of molecular resin coat over cellulose based matrix. Fatty oil aerosol formation in cooking, air lifting due to nature consciousness, and adsorption over natural fiber polymer composite lamina evolve stick-slip tactile friction. A material energy balance of fatty oil aerosols with amalgamation with environmental particulate matter is a mechanochemical mechanism for transformation of smooth surface to sticking and slipping surface. The case study of molecular adsorption is prepared during SARS-CoV-2 pandemic in India for fundamental research in interdisciplinary content for assessment of energy balance.

Conclusions

Author have completed a diverse academic survey for structuring an academic perspective of adhesion, friction, and lubrication for synchronization of materials energy balance. Supramolecular forces regulate tribology for functional engineering surfaces, interfaces, and interphases. Promotion of green technology and advancement of sustainability have been safeguarded by author in amalgamation of heterogeneity. Nature inspired materials are innovative for transformation of engineering surfaces as per the requirement for socioeconomic parameters.

Author contribution

Author has prepared a personal viewpoint or academic perspective as per the requirement for achievement of performance indicators. Author is inspired by heterogeneity profoundly a diverse and inclusive content is structured for rendering, viability, and academic integrity

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