Impact of State Variables for Assessment of Energy Dissipation

Pankaj Tomar

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P. TOMAR
IGDTUW/GGSIPU, India
https://orcid.org/0000-0002-7040-2844

Abstract

Tribology is a an emerging socioeconomic, scientific, and academic domain for optimization of energy loss at rubbing contacts during 21st century. Adhesion, friction, lubrication, wear, and mass transfer due to biodegradation are fundamentally involved for designing of functional interfaces. Covid#19 pandemic is a global alarm for synchronization of carbon footprints evolved from transport sector in modulating a novel materials and energy interface.

1. Introduction

The 2030 agenda of SDGs is a common political shared blueprint for the achievement of sustainable development goals [1]. The Paris Agreement/COP26 in Glasgow 2021 affirmed energy sectors to reduce carbon footprints for decarbonization and facilitate the much-needed paradigm shift towards a low carbon socioeconomic system [2]. The hundreds of billions of US dollars can be saved by energy efficient tribological operations-an estimated 1.3% to 1.6% of a nation's gross domestic product [3]. The virtual realities evolution in digital era never denied the contribution of Tribology at rubbing mechanical interface in transport sector, energy generation, and residential buildings. The word "TRIBOLOGY" is coined by Hans Peter Jost in a socioeconomic and technical report highlighted the friction, wear, and corrosion to the United Kingdom economy (1.1 to 1.4 %) of gross domestic product [4]. A study to determine the energy saving of tribology related to the road transportation, power generation, turbomachinery, and industrial machinery of conserving up to one tenth of the total U.S. energy consumption in terms of the 1976 energy expenditure rate of over $16 billion economy [5]. In passenger cars 1/3rd of the fuel is expended to overcome friction in the engine, transmission, tires, and brakes for saving 117 gigalitre fuel and 290 Mt CO_2 anthropogenic load by research and development [6]. Eco-tribology in surface modification is seen to be an effective engineering technology for sustainable societies such as bio-inspired surface texturing for tribo-materials designing, low surface energy or hydrophobic surface innovation, and deficit budget of materials energy dissipation [7]. The solid biomass, liquid biofuels, and biogas may create a primary energy supply for an elementary source of fuel in industry and transport in reducing anthropogenic load over urban cities.

The study on the prediction of car fuel savings showed that the fuel loss at tribological contact of tires ~7.5% at 60 km/h and the reduction in tire rolling resistance to fuel savings lies between 20 to 25% in the case of constant velocity running [8]. The estimated 30% or a little more of the energy consumed in the transportation sector of US is spent to overcome losses due to friction and wear for materials-energy savings ~11% across the transportation, industrial, and utilities sectors [9]. The condition monitoring of wear protection saves 8.8 Gt of estimated resources and a part of saving potential of 30-40 % friction losses reduce 2.66-4.93 Gt global CO_2 emission [10]. The CO_2 capture and storage, electrochemical conversion of economical fuels, and polymerization of carbon molecules may have a little role for reduction of 7 Gt CO_2 load evolved from transport sector [11]. The nature inspired surfaces, interfaces, and interphases may be viable for innovation or strengthening of science-economy-environment boundaries [12]. Nature is evolving surfaces from millions of years for rationalization of interfacial energy dissipation of diversity of biology in a conscious umbrella of biosphere. The modulation of surface characteristics ease in lowering surface energy and surface tension for producing engineered materials useful for defeating environmental reaction of third bodies [13]. Smithers report on the global packaging market value will increase from $917 billion in 2019 to $1.05 trillion by 2024 with a compound annual growth rate (CAGR) of 2.8% Asia is the largest packaging consumer than America and Europe [14]. Cellulose is a natural and the abundant biodegradable polymer over planet in terms of economy for the quest of sustainable packaging applications. Surfaces in interacting motion are at the foundation of the critical energy-efficiency properties of friction, lubrication, and wear, of all energy systems of rubbing interfaces.

2. Self-cleaning mechanism

The self-cleaning mechanism is attributed to the removal of third bodies by impacting or rolling water droplets due to the action of external *in situ* forces of nature. The rough water repellent *N. nucifera* leaves have inherent self-cleaning mechanism against environmental contaminants for rolling down of water droplets in general called "Lotus-Effect" carry scientific and biological importance for producing engineered functional surfaces [15]. The superb self-cleaning mechanism of lotus leaf is evolved academic and scientific inertia for designing of superhydrophobic engineered nanomaterials in providing non-stick performance for socioeconomic applications [16-17]. The design and manufacturing of self-cleaning surfaces have been creating an area of active research based on micro- and nanostructure such as the lithography, etching, and deposition for producing superhydrophobic surfaces [18]. The self-propelled jumping condensate on superhydrophobic surfaces is a mechanism of electrostatic van der Waals and/or capillary bridging attractions for removing contaminants of hydrophobic, hydrophilic, organic, inorganic particles effective than other removal mechanisms such as wind, gravity, and vibrations [19]. Melamine (1, 3, 5-triamino-2, 4, 6-triazine) formaldehyde is an amino resin and thermosetting polymer in providing transparency, hardness, thermal stability, abrasion resistance, moisture resistance, surface smoothness, economic values for promotion of green tribology [20]. The nature is not able to synthesize perfluorinated macromolecular structure for the determination of their surface chemistry create new scientific innovation to design superoleophobic materials using fluorinated compounds useful for surface modulation of non-stick superhydrophobic and superoleophobic substrates [21]. The hydrophobic polytetrafluoroethylene is a functional non-stick coating for oleophobic substrate in lowering surface energy then water few layers molecular surface or approximately one third of water surface [22]. The melamine formaldehyde is promising functional opportunities in the electrical appliances, household appliances, tableware, adhesives, paints, packaging segment, coatings, laminates, sanitary ware, and automotive decorative surfaces.

3. Real area of contact

The mechanics and mechanism of real area of contact have been introduced by 'Bowden & Tabor' for ignoring apparent area of contact of mechanically interlocked asperities shearing in resolving complexities of elastic physiochemical friction boundaries of rubbing substrates [23-24]. Amontons′ friction laws 1699 stipulated by the work of Leonardo da Vinci state that the existence of a proportional coefficient of friction force and the nominal load, and that the friction force is independent of apparent contact area is invalid in many real engineering substrates in the field of soft tribology [25]. Experiments have showed that the friction force is proportional to the true area of contact irrespective of Amontons′ laws obeyance for elastomers surface topography inclusion [26]. The mechanical interlocking plays a role in explain real area of contact or stick-slip friction borrowed from the idea of McBain and Hopkins 1925 to such mechanical substrates as wood, bitumen, and porous pottery [27-28]. The influence of elastic solid bodies contact is interpreted in terms of adhesion energy of soft mechanical substrates [29]. Electroadhesion at man and machine is an advanced scientific approach for applicability of peeling action and surface energy in engineering devices [30]. The real contact area and the electroadhesion force depend on skin surface roughness, the nature of the touch screen coatings, and interfacial environment for generating tactile feedback on touchscreen [31]. Frictional is perceived for sensory cues in daily life when finger rubs against the screen of a smartphone in generation of electromechanical signals by the complex contact mechanics occurring at the fingertip interface during tactile interaction [32]. The real area of contact, surface science, viscoelasticity of surface, and severe energy losses ease in deviation of classical law of friction.

Personal protective equipment is an essential biomedical interface capable in fighting viruses such as goggles, visors, and respirator masks in stick-slip skin friction zone (μ~1.14) cause for skin injuries e.g., contact dermatitis, skin tears, urticaria, blisters, and pressure ulcers [33]. The relative importance of skin friction has been observed in everyday situations for the design process of consumer products, personal care, and sports includes optimising the manufacturing costs, product aesthetics, durability, functionality, and the degree of discomfort of real area of contact [34]. Plantar skin is to withstand the external stresses in physical activities for stick-slip tribological characterization during external mechanical stresses such as a role for evolution of textured surface in sticking or slipping environment [35]. Human skin is a complex stick-slip interface over the entire body responsible for many functions such as the protection against foreign intrusions, thermo-regulation, hydration lubrication for the bio-tribological properties of human skin contact with various materials, lubricants, cellulose based fabrics, and atmospheric conditions [36]. Human skin is a stratified tissue of hypodermis, dermis and epidermis or outer interface called stratum corneum in water scarcity compared with viable tissues characterized by a gradient that transform rational skin surface to the stick-slip pathological tribological interface [37]. The stick–slip friction of finger pad sliding on wet, smooth glass have been expressed as a function of normal force and sliding velocity using a tri-axial force plate for investigation friction coefficients during stick–slip (0.53±0.21) i.e., 30% lower than static friction coefficient (0.78±0.35) of human skin [38]. The knowledge of the electroadhesion of human skin with fabrics diversity is essential to improve the materials for friction coefficient in broad range (0.26-0.79) under sliding or rubbing contact in the formation of skin injuries caused by shear forces in tribological boundaries over long periods of time [39]. The inclusion of personal care lotion, olive oils, hydration lubrication due to energy expenditure, and natural fibres manufactured fabrics optimize friction at human skin or fabrics surfaces of pathological interface.

4. Hydrolysis and bioadsorption

Hydrolysis is a chemical reaction in which a water molecule breaks chemical bonds over substrates whereas bioadsorption is the cleavage of biomolecules of substrates in transient mass transfer from biochemical organisms. The biomaterials market is fast emerging from $91.08 billion in 2021 to $103.18 billion in

2022 at a compound annual growth rate of 13.28% and the projected reach $180.36 billion in 2026 at a compound annual growth rate of 15.03% based on metallic, natural, esters, and ceramics biomaterials [40]. The biodegradable device implanted in the body maintain mechanical properties until it degraded, absorbed, and excreted by the body from hydrolysis of the polymer degradation or bioadsorption [41]. Biocompatibility, biodegradation rate, U.S. Food and Drug Administration (FDA) approval, to provide better interaction with biological surface, and suitability for export to countries have encouraged poly(lactic-co-glycolic) acid (PLGA) as a novel biomaterial for biomedical applications [42]. The scaffold is needed as an adhesive substrate for the implanted cells to facilitate cell adhesion, cell growth, and cell differentiation functions of a large surface to volume ratio with (PLA) mechanochemical properties [43]. The polylactic acid (PLA), poly(lactic-co-glycolic acid) (PLGA), poly(ε-caprolactone) (PCL), poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV), poly-3-hydroxybutyrate (or poly-β-hydroxybutyric acid, PHB), poly(propylene carbonate) (PPC), poly(propylene fumarate) (PPF), and poly(butylene succinate) (PBS) polyesters provide hydrophilicity for designing of biomedical devices [44]. The restoration of surface features in tissue engineering and regenerative medicine or the design and manufacture of new tissues for the functionalities of impaired organs depend on the extracellular matrix scaffolding for friction, lubrication, and wear for interacting surfaces [45]. Biodegradable materials are preferred in medicine, packaging, agriculture, and other areas for designing or manufacturing of biodegradable synthetic or natural polymers [46]. The biomedical engineering has transformed biodegradable polymers for manufacturing of medical devices for biocompatibility of scaffolds in the economic field of biotribology.

Conclusions

The socioeconomic and ecological impacts of adhesion, friction, lubrication, and wear are ubiquitous in fast emerging developing economy. The materials and energy balance of tribology surface have been numbered for sustainable pattern or sustainability.

1. The rationalization of source and sink domain for achievement of mechanical work at man and machine surface and interface as per the harmony of 2nd law of thermodynamics
2. "Wear" is the irreversible matter loss for functional failure of mechanical surfaces for upgradation of product life
3. The classical laws of friction have been violated for soft tribology in presence of interfacial diffusion, viscoelasticity, and real area of contact

4. The real area of contact is witnessed in assessment of stick-slip friction of pathological human skin, seismology, sports items, and tactile friction of man/machine interface
5. Bio-adsorption and hydrolysis of biomaterials attained an economic inertia for last five decades in biomedical applications

Author Contribution

Author wrote paper for achievement of performance indicators

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