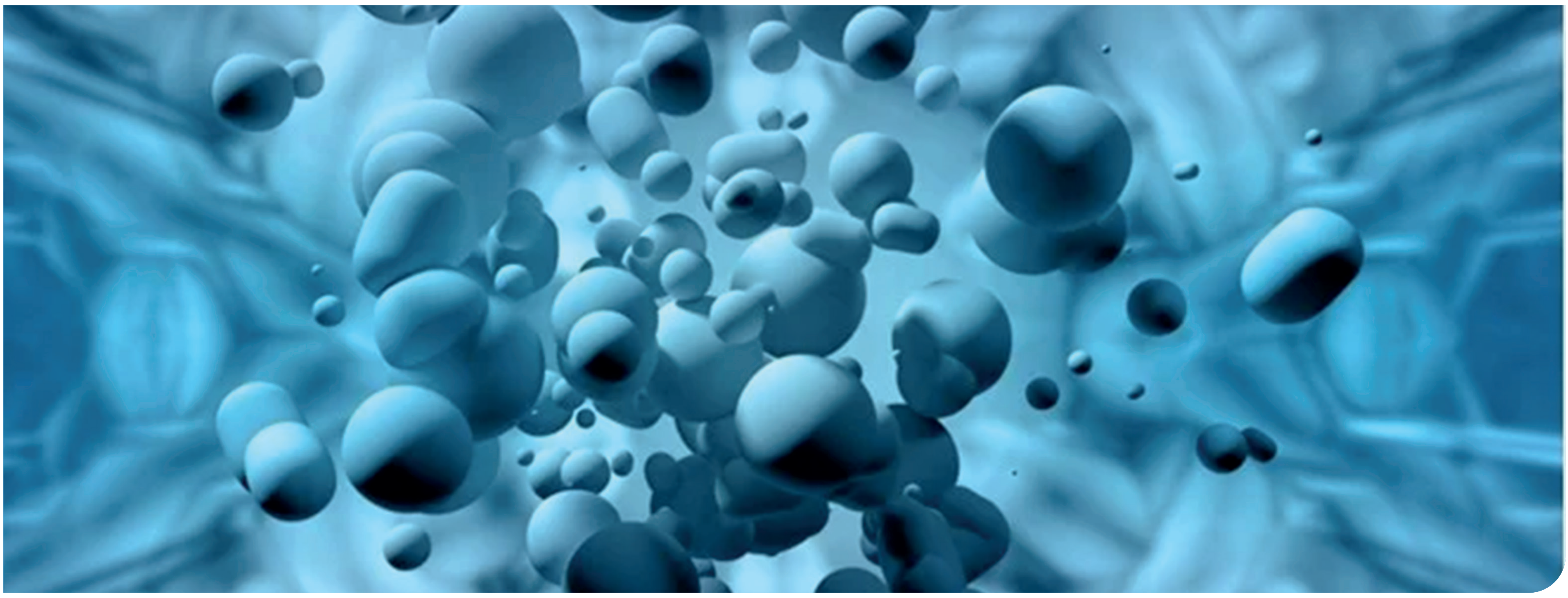
INNOVATIVE USE OF NANO PARTICLES TO DEVELOP AN ENVIRONMENT-FRIENDLY WATER-BASED HIGH-PERFORMANCE LUBRICANT



Around 25% of energy consumption in this world is because of friction among two different surfaces, and a study conducted by the International Energy Agency suggested that for every person, frictional losses amount to 5000 kWh/yr. Most of the loss is due to material wear caused by friction in the machines' used by individuals daily [1,2]. Furthermore, 2-3% of the EU's GDP is spent on replacing damaged machines due to excess friction [3]. Most of the world depends on traditional oil-based lubricants, which contain Sulfur (s), Zinc (Zn), Phosphorus (P), etc. Over the years, as pollution rises, there has been an increase in concern among environmentalists, therefore, many governments have passed laws to limit the use of certain efficient lubricants and additives to minimize environmental impact [3]. Thus one of the lubricant industry's current challenge is to design a new efficient, high-quality, environment-friendly product that can reduce friction and help save the planet from the adverse effect of pollution. This paper reviews recent advancements in the industry and discusses promising solutions proposed by the researchers studied.

In recent years water-based lubricants are gaining popularity because of their versatile use. Operations like milling, drilling, etc., require cooling and proper lubrication, and water-based lubricants can serve as coolants because of their high thermal conductivity. Water-based lubricants are also environment-friendly, and their high fluidity makes them a great alternative [4]. However, water needs additives to enhance its lubrication properties, and over the years, oil has been used as an additive, but it doesn't solve the environmental issues associated with traditional grease-based lubricants [5,6]. Therefore, it is necessary to look for alternative additives, and recently many researchers suggested adding nanoparticles might be the solution everyone is looking for. Adding nanotubes improves the quality of lubricants, and environmental damage is minimized [7,8].

According to researchers, IFWS2 is potentially a tribologically superior water-based additive. Ti–6Al–4V has various industrial applications due to its high ductility and corrosion resistance; however, it is difficult to machine material. A study led by Bhowmick et al. investigated the effects of WS2 nanoparticles mixed with cutting fluids and found that it not only achieves a stable coefficient of friction (COF) but also reduces cutting force which results in a decrease in wear during the orthogonal machining of Ti–6Al–4V. The study tried different concentrations of WS2 under a constant load of 5N.

The study found that the addition of 1wt% of WS2 with WC-CO produced the lowest COF in both sliding and steady states [figure 1]. After that, an increase in concentrations led to an increase in COF, therefore, it can be concluded that the addition of <1wt% reduces COF by at least 25% compared to plain lubricants.

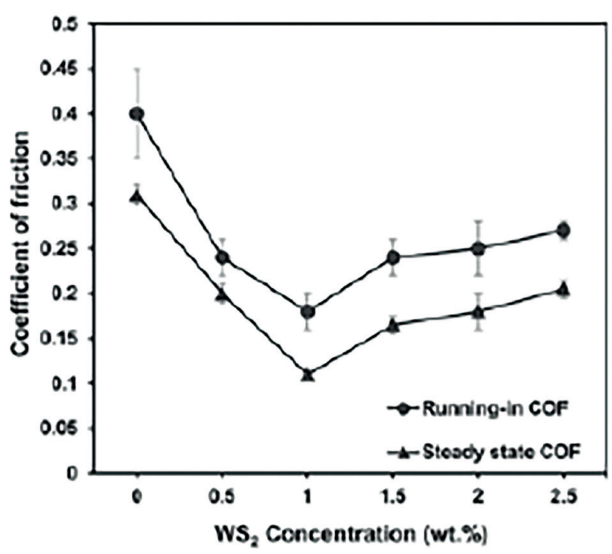


Figure 1: Variation of running-in and steady-state COF for CF with different WS2 concentrations [9].

The study also showed that cutting force remains constant throughout the cutting process regardless of the speed when 1wt% of WS2 is added. All of these are due to the addition of WS2 and WO3, which forms protective layers which lead to lower surface roughness compared to plain lubricants (CF) [9].

A study led by Liang et al. investigated the in-situ exfoliated graphene for water-based lubricants, and the result shows exceptional mechanical stability and frictional and anti-wear properties. Although previous studies have investigated functionalized graphene as it is hydrophilic, it is easy to add to water. This study used pristine graphene (0.0024–0.011 wt%) because of its superior quality in spite of its hydrophobic nature. The researchers added Triton X-100(C34H62O11) as a stabilizer (0.1 wt%) to battle the hydrophobicity and enhance the quality of the lubricants [8].

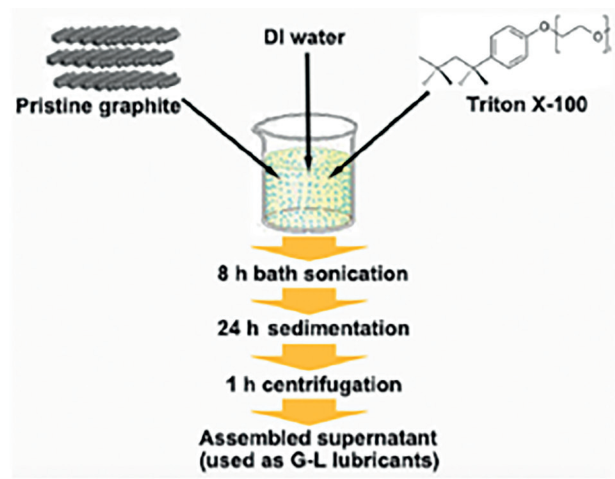


Figure 2: The fabrication process [8]

They used different concentrations of graphene and found that adding graphene significantly reduces the wear scar and frictional coefficient. Figure 3a shows the addition of 110 μg/ml graphene leads to a reduction of ~81.3% in friction coefficient than DI water, however, the graphene oxide(GO) sample didn't perform very well compared to graphene. Also, the smooth graph indicates that the addition of graphene leads to consistent friction, whereas the other samples' graphs fluctuate [8].

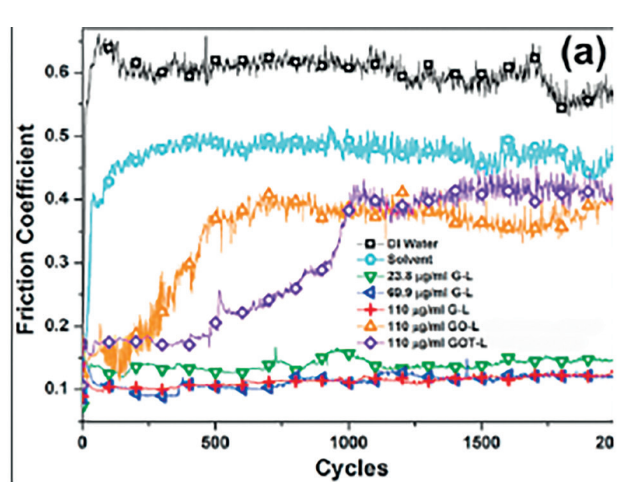


Figure 3(a): Friction coefficient of different samples throughout the experiment [8]

To further study the viability of in-situ exfoliated graphene for water-based lubricants, the researchers studied the anti-wear properties and found that the addition of 110 μg/ml G-L

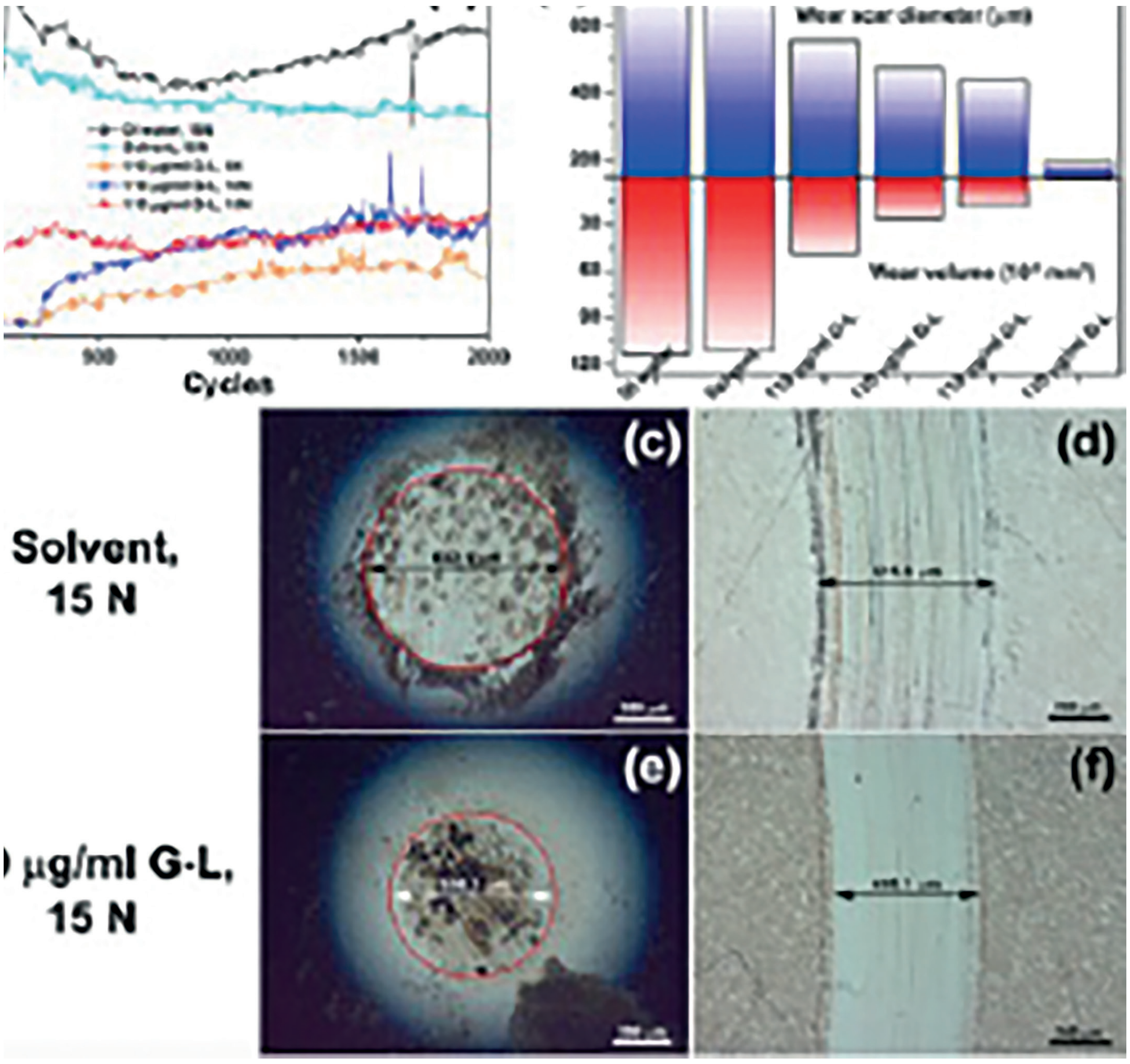


Figure 4: Properties when heavy loads are applied [8]

decreases wear scar diameter (WSD) by 61%. The study also claimed that increasing the concentration of graphene leads to the enhancement of anti-wear properties, for example, adding 110 µg/ml GO-L causes the scar to decrease by 71% compared to DI water.

One of the significant weaknesses of water-based lubricants is their inability to perform under heavy loads, and this study also improved their performance under higher loads (5N, 10N, 15N). The study shows that higher loads lead to an increase in friction coefficient and wear scar, however, under 15N loads G-L sample reduces frictional coefficient by 58.7% compared to DI water and improves anti-wear properties by 55.8% [figure 4].

All of these improvements may be attributed to the added graphene because it helps to form an adhesive layer and protective layer at the contact zone. The addition of Triton X-100 improves the viscosity of the lubricants and increases the wettability, and decreases in contact angle, leading to a reduction of impact on the surface when force is applied [8]. This study shows that pristine graphene-based water lubricants have potential and certain nano additives could have a bright future.

A study led by Najiha et al. investigated water-based TiO2 nanofluids to enhance the cutting performance in Aluminum milling. TiO2 materials are known for their exceptional anti-wear, load-carrying capacity, and frictional performance [10]. This study took both mechanical stability and environmental sustainability while designing the lubricants, and the result is promising. The study was conducted at different cutting speeds using various concentrations of TiO2. The results showed that as the flow rate of the lubricants increased, the adhesion decreased, and higher concentrations of TiO2 didn't translate to higher protection against friction. The study also tried to build a sustainability index for the lubricants, but because of the lack of data, the result cannot be considered viable [10].

Another study conducted by Devireddy et al. used similar lubricants to enhance the performance of automobile radiators. They used 40% ethylene glycol and 60% water mixed with various concentrations (0.1%, 0.3%, 0.5%) of TiO2 nanopowder. Over the years, hybrid vehicles are becoming more mainstream, and there is an emphasis on clean exhaust gas regulation due to these water-based lubricants being the most prominent contender to replace the conventional lubricants used as coolants in automobiles' radiators [11].

To understand the extent of the thermal conductivity of the fluid, the study found that the increase in nanofluid concentration led to a decrease in outlet temperature showing the effectiveness of the lubricants as a coolant. When the concentration of TiO2 was 0.5%, the heat enhancement increased by 34.12% compared to when the concentration was 0.1%. It shows that when concentrated nanofluids achieve a higher heat coefficient, it allows working fluids in the radiator to be cooler, leading to an increase in efficiency [11].

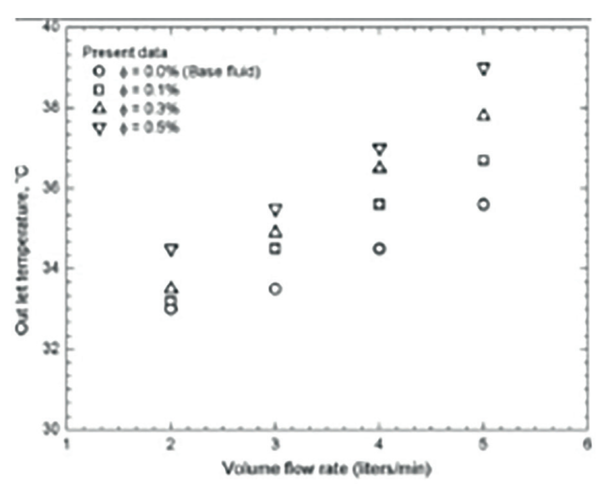


Figure 5: Comparison of the radiator cooling performance using nanofluid [11]

Although the study found that nanofluid increased thermal conductivity and improved the performance of automobile radiators, however, we need more theoretical and experimental data to solidify the claims and investigate the commercial potential of such lubricants.

In recent years, magnesium alloy becoming a major part of the automobile industry because of its use in making lightweight components for cars, airplanes, electronics, etc. The current fabrication method of commercial magnesium alloy is not advanced, and unnecessary friction during the process leads to poor quality, a short life span, and inhomogeneous deformation [12,13]. Research led by Xie et al. proposes a combination of SiO2/Graphene as an additive to water-based lubricants to achieve better functionality and enhance the mechanical stability of magnesium alloy. They tested the frictional properties of the additives for rolling magnesium alloy and found them to be effective in reducing frictional coefficient (FC) and wear volume (WV). Liang et al.'s research concluded that in situ exfoliated graphene can effectively reduce friction and wear volume, and SiO2 is known for its low cost and high heat resistance. Therefore, there is a chance that a combination of SiO2/Graphene will increase the rolling action between interacting surfaces and improve the fabrication process of magnesium alloys [11,13].

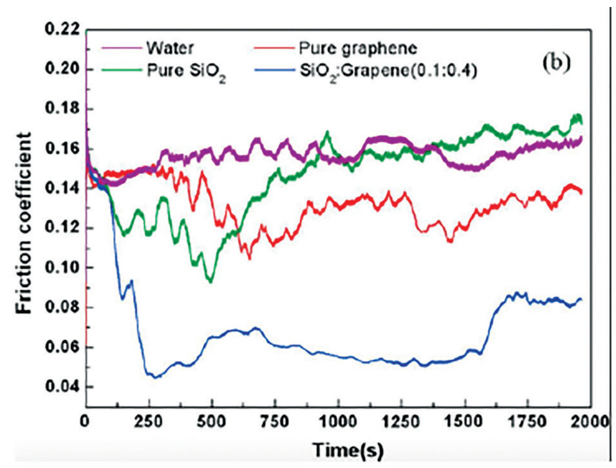


Figure 6: Change in friction coefficient with the sliding time (3 N, 0.08 m/s, 0.5 h) [13]

Figure 6 shows significant improvement after adding nanoparticles to the water-based lubricants. The addition of SiO2 to the pure water translates into a 13% reduction in friction coefficient, and pure graphene performs better than pure SiO2, but the combination of SiO2/Graphene outperforms both of them. When the SiO2/Graphene ratio is 0.1:0.4, it showcases 53.7% lower FC than pure SiO2 and 48.5% less than pure graphene. It proves that a combination of SiO2/Graphene is a superior additive to SiO2 and graphane alone [13].

Similarly, a 0.1:0.4 ratio of SiO2/Graphene reduces the wear volume from 26.7 mm3 (pure water) to 4.86 mm3 displaying its exceptional anti-wear properties. The 2D cross-section showed that the scars were shallow when the combination of SiO2/Graphene was used compared to pure SiO2 and Graphene [figure 7].

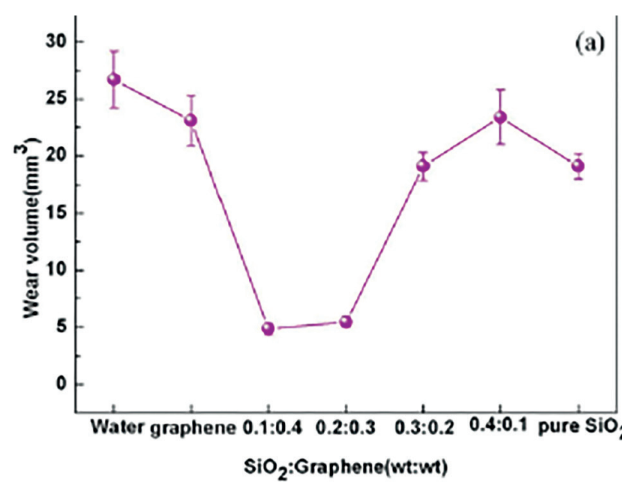


Figure 7: Average wear volume of different samples [13]

One of the major drawbacks of water-based lubricants is their inability to withstand higher loads as the contact area between both surfaces increases and FC also goes up. However, a combination of SiO2/Graphene showcases its load-carrying capacity, as the FC was always below 0.1 for the additive. Also, the combination has the lowest contact angle, which proves that SiO2/Graphene is able to form a better protective layer because of the difference in wettability of the interacting surfaces. All these indicate its potential to become a commercial product in the lubricant industry [14].

Considering all this research, it can be said that water lubricants may become interesting products to overcome the current environmental issues sometimes associated with grease and other oil-based lubricants. To get the best outcome, nanofluids might have to play as possible additives to enhance thermal conductivity, reduce frictional coefficient, and minimize wear volumes [14]. The studies listed here suggest that proposed solutions have potential, however, there should be more research and data to prove the commercial viability of these lubricants.

References

1. Holmberg, Kenneth, and Ali Erdemir. "Influence of Tribology on Global Energy Consumption, Costs and Emissions." Friction, vol. 5, no. 3, Sept. 2017, pp. 263–284, 10.1007/s40544-017-0183-5.

2. International Energy Agency. Key World Energy Statistics 2015. 2015.

3. Kalin, Mitjan, Marko Polajnar, Maja Kus, & Franc Majdič. "Green Tribology for the Sustainable Engineering of the Future." Strojniški vestnik - Journal of Mechanical Engineering [Online], 65.11-12 (2019): 709-727. Web. 25 Oct. 2022

4. Peng, Yitian, Yuanzhong Hu, and Hui Wang. "Tribological behaviors of surfactant-functionalized carbon nanotubes as lubricant additive in water." Tribology Letters 25.3 (2007): 247-253.

5. Tomala, A., et al. "Tribological properties of additives for water-based lubricants." Wear 269.11-12 (2010): 804-810.

6. El Baradie, M. A. "Cutting fluids: Part II. Recycling and clean machining." Journal of materials processing technology 56.1-4 (1996): 798-806.

7. Cho, Dae-Hyun, et al. "Evaluation of hexagonal boron nitride nano-sheets as a lubricant additive in water." Wear 302.1-2 (2013): 981-986.

8. Liang, Shuaishuai, et al. "In-situ exfoliated graphene for high-performance water-based lubricants." Carbon 96 (2016): 1181-1190.

9. Bhowmick, Sukanta, et al. "Effect of WS2 particles in cutting fluid on tribological behaviour of Ti–6Al–4V and on its machining performance." Tribology-Materials, Surfaces & Interfaces 15.4 (2021): 229-242.

10. Najiha, M. S., M. M. Rahman, and K. Kadirgama. "Performance of water-based TiO2 nanofluid during the minimum quantity lubrication machining of aluminium alloy, AA6061-T6." Journal of cleaner production 135 (2016): 1623-1636.

11. Devireddy, Sandhya, Chandra Sekhara Reddy Mekala, and Vasudeva Rao Veeredhi. "Improving the cooling performance of automobile radiator with ethylene glycol water based TiO2 nanofluids." International communications in heat and mass transfer 78 (2016): 121-126.

12. Jiménez, Ana Eva, et al. "Surface coating from phosphonate ionic liquid electrolyte for the enhancement of the tribological performance of magnesium alloy." ACS Applied Materials & Interfaces 7.19 (2015): 10337-10347.

13. Xie, Hongmei, et al. "Tribological performances of SiO2/graphene combinations as water-based lubricant additives for magnesium alloy rolling." Applied Surface Science 475 (2019): 847-856.

14. Pop, Eric, Vikas Varshney, and Ajit K. Roy. "Thermal properties of graphene: Fundamentals and applications." MRS bulletin 37.12 (2012): 1273-1281.

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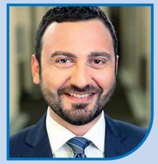
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