Solid Lubrication in Machine Components for Dry Running Systems

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Introduction

Tribology is the study of the interaction between contact surfaces, which include properties like friction, lubrication, and wear. The reliability of industrial machinery and automobiles is affected by the force of friction on the mechanical parts. The force of friction leads to wear and an increase in the temperature of the machine which not only affects the efficiency but also affects the consumption of power of the machinery [1]. To prevent this, a lubricant is usually applied to the surface. Traditional lubricants are mixtures of hydrocarbons derived from crude oil and various additives. It is then applied between two contact surfaces to alter the tribological properties, such as anti-wear and friction. Examples of additives are graphite, molybdenum disulfide, tungsten disulfide, and boron nitride [1]. The type of solid lubricant used determines its effectiveness because different lubricants will have different load capacities and will work effectively in different temperatures. An ideal lubricant has a low coefficient of friction, improves wear resistance, and works well under extreme pressure. Examples of solid lubricants include molybdenum disulfide and graphite, however, molybdenum disulfide is more commonly used because of its low coefficient of friction, high load capacities, high wear resistance, and improves the surface roughness of the surface when compared to graphite 625 and graphite 325 [1]. Molybdenum disulfide was also found to perform better than metallic chromium because of its lower coefficient of friction [2].

Four-Ball Tester and Extreme Pressure and Temperature Properties

The four-ball test can be used to measure how well the lubricant performs which can be used to determine which type of lubricant is applied to the machinery. The four balls are placed in a tetrahedral position with three balls in a fixed position at the bottom and the top ball rotating against them. This test is done under extreme pressure (force of 392 N) and high temperatures (75°C). According to the ASTM testing method, the fourth ball rotates for an hour at 600 rpm [3]. After this, the surface is measured for wear scars which are used to determine the performance of the lubricant. In addition, the fourth ball will be rotated at 600 rpm for ten-minute intervals. The coefficient of friction is measured using the wear scars after each ten-minute interval. The Benchtop Four-Ball Wear and EP Tester, which fits ASTM guidelines, can be used to perform these tests.

Extreme pressure lubricants are applied on parts that experience extreme pressure and are used to decrease wear on these parts. To determine the extreme pressure properties of a lubricant, a four-ball wear and ep tester machine can be used. The extreme pressure properties are also measured at different conditions like frequency, temperature, and ball and disk material. This method of testing uses one steel ball which rotates against three stationary balls with lubricant covering the three steel balls. It rotates around 1760 rotations per min under conditions around 65-95 degrees Fahrenheit. This test method differentiates between lubricating fluids with different extreme pressure properties [4].

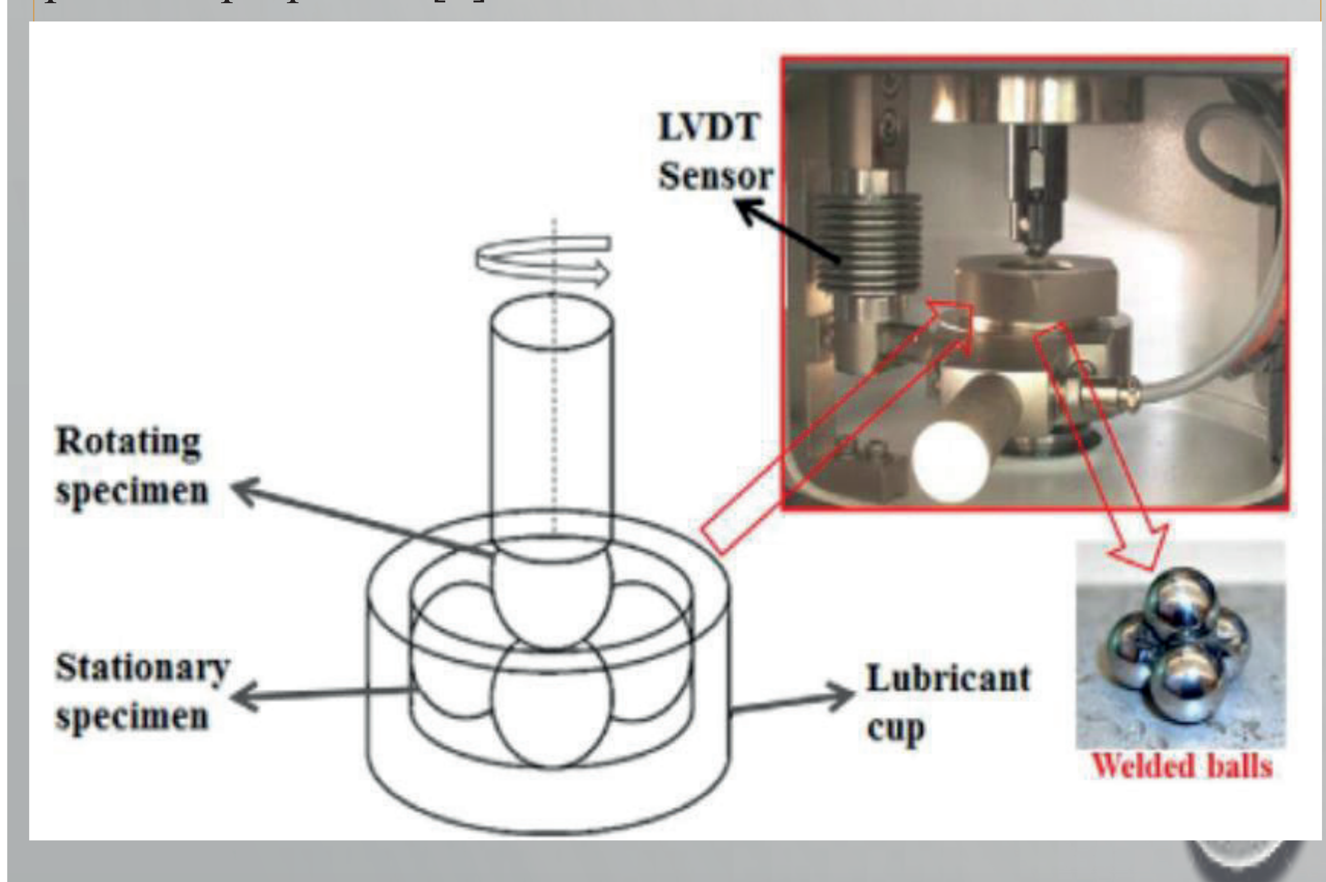

Figure 1 depicts what is occurring during the four ball test and the extreme pressure test [1]. The Benchtop Four-Ball Wear and EP Tester could be used to replicate this position and perform the four ball test and extreme pressure test.

Solid Lubrication

Through EDX (Energy Dispersive X-Ray Spectroscopy) spectrum analysis, molybdenum disulfide coating was found to contain Mo, S, O, and C during tribological testing. The coating is usually applied through the spraying technique, where the lubricant is sprayed onto the surface because it improves friction and wear resistance performance [2]. During the rotary wear friction test, which simulates the rotational motion found in tribology mechanisms, the ball coated with the solid lubricant releases MoS_2 and other hard composite wear particles which reduces the friction between the contact surfaces and improves the ball's resistance to wear [2]. In another experiment regarding MoS_2, it was discovered that the particle size could affect its performance. For example, under conditions of high loads and high speed, micro MoS_2 works better than nano MoS_2. However, under conditions of low loads and low speed, nano MoS_2 works better than micro MoS_2 [6]. This showed that the different sizes of lubricants work better under different conditions. The film thickness between the contact surfaces when MoS_2 was applied was investigated. According to figure **2**, it was discovered that as the additive particle size of the base oil was increased, the average lubricant film thickness also increased. Additionally, as the concentration of MoS_2 in the base oil increases, the coefficient of friction decreases [1].

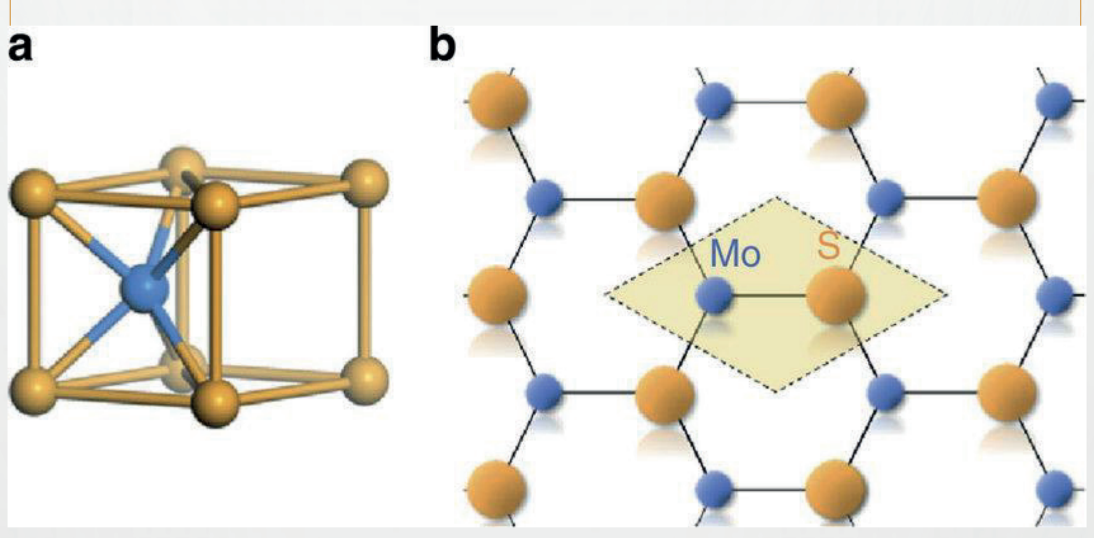

Figure 2 shows the crystalline structure of MoS_2 [8].

WS_2 nanoparticles can be used as a lubricant additive to improve wear resistance and reduce the friction of base oils. WS_2 was found to perform best when the temperature is around 273 degrees Celsius to 425 degrees Celsius. Lamellar, a layered structure, and spherical WS_2 were used as lubricant additives. The Stribeck curve for lamellar WS_2 indicates that for the lamellar WS_2, the coefficient of friction increases as the load increases because the lubrication changes state from fluid to mixed due to the thick oil film. The Stribeck curve for the spherical WS_2 demonstrates that for the spherical WS_2, the coefficient of friction decreases as the load increases because it has a fluid lubrication state. Additionally, the spherical WS_2 lubricant has rolling friction because of its spherical shape which reduces the coefficient of friction. Therefore, spherical WS_2 performs better than lamellar WS_2 which means that the crystal structure of a lubricant affects the performance of the lubricant [6].

Conclusion

Lubrication is applied to machines to decrease the coefficient of friction which in turn decreases friction, increases the efficiency of machines, and improves wear resistance. Lubricants can also have additives that help enhance the performance of the lubricant. The size and shape of the lubricant can also affect its performance. To measure the performance of the lubricant the four-ball test, the SRV test method, and the wear test can be implemented.

Tribofilms

Tribofilms are formed to help improve the tribological properties. CuO and MoS_2 nano lubricants were found to form tribofilms which help reduce wear. To further investigate the formation of tribofilms, micro-Raman spectroscopy was performed. It was found that the tribofilms were formed because of the reaction between the material and the additives. It was also discovered that the tribofilm formation had a wear protection mechanism that affected the contact geometry [7].

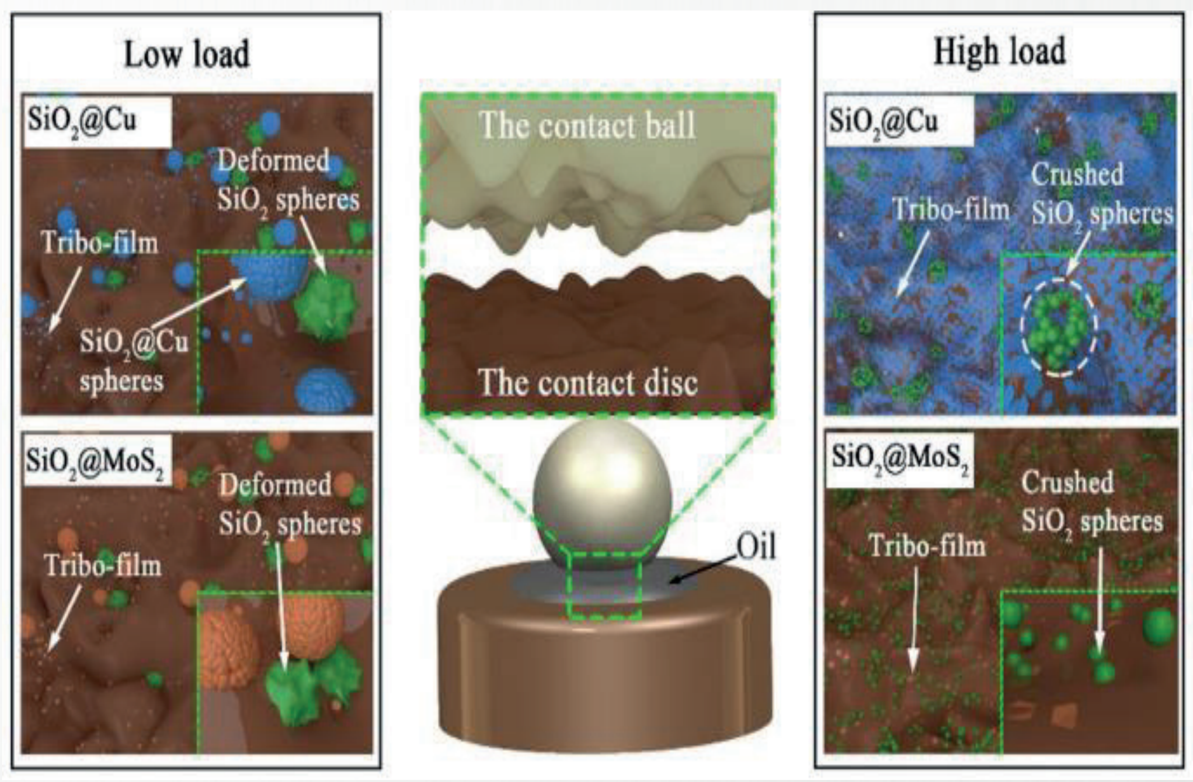

Figure 3 indicates the formation of tribofilms with different lubricants [9].

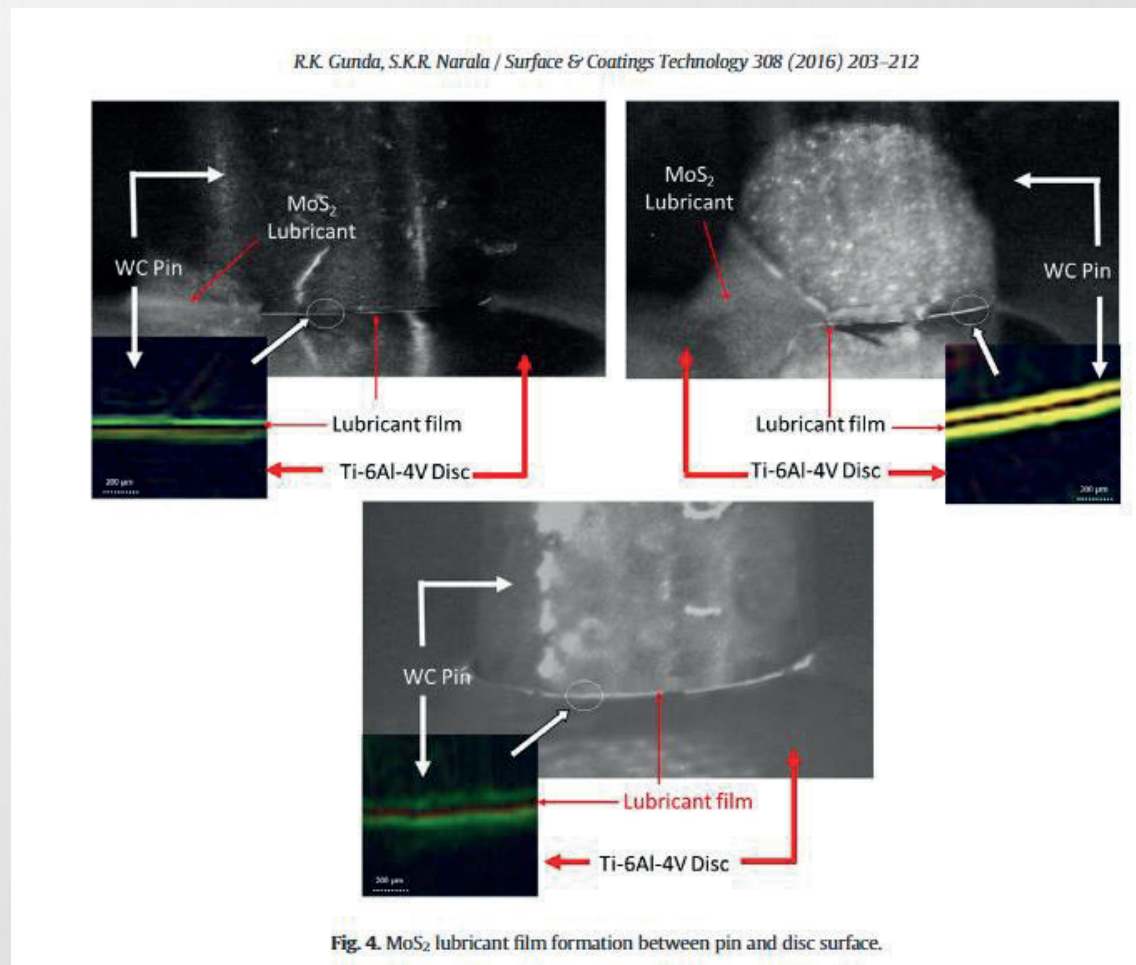

Figure 4 shows the formation of tribofilms after MoS_2 was applied. [1]

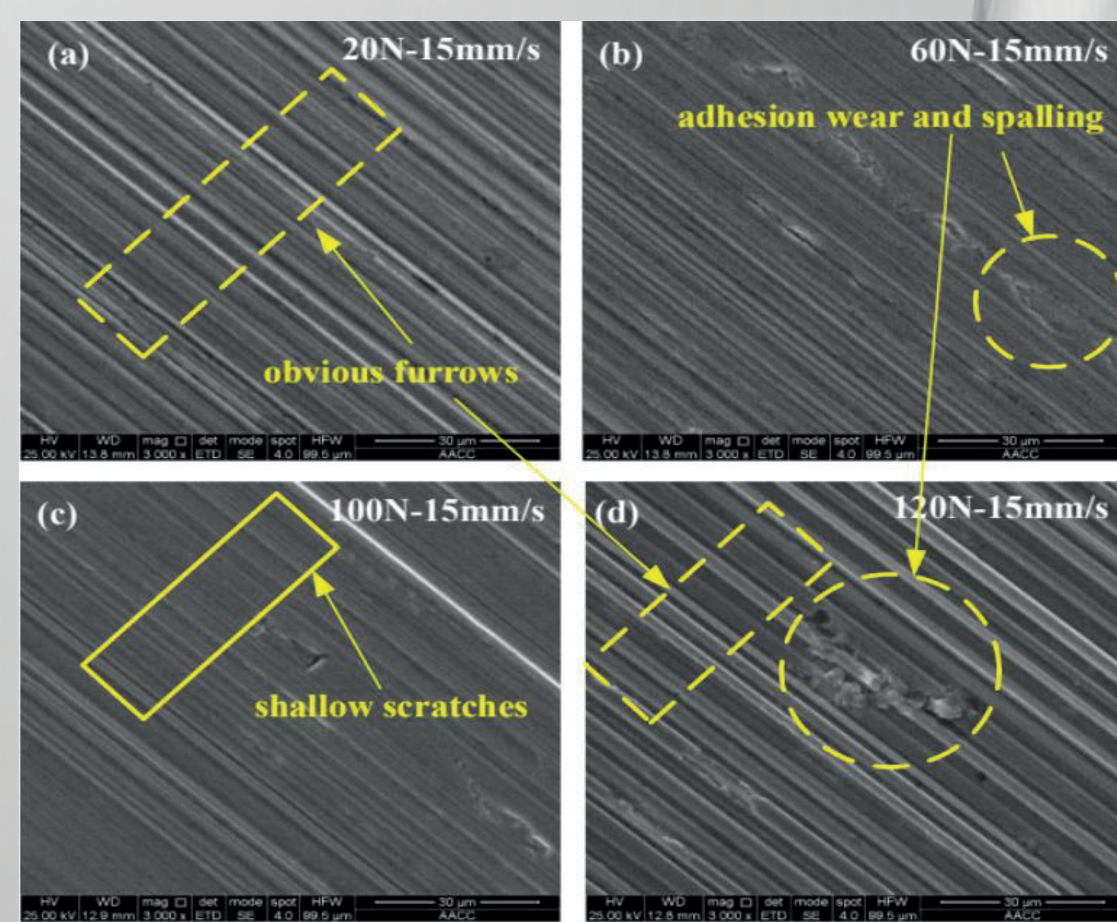

Figure 5 shows the different types of wear scars [6].

References

[1] Gunda, R. K., & Narala, S. K. (2016). Tribological studies to analyze the effect of solid lubricant particle size on friction and wear behaviour of ti-6al-4v alloy. *Surface and Coatings Technology*, *308*, 203–212. https://doi.org/10.1016/j.surfcoat.2016.06.092

[2] Ananth, M. P., & Ramesh, R. (2017, May 9). *Sliding wear characteristics of solid lubricant coating on titanium alloy surface modified by laser texturing and ternary hard coatings*. Transactions of Nonferrous Metals Society of China. Retrieved October 9, 2021, from https://www.sciencedirect.com/science/article/abs/pii/S1003632617600967.

[3] ASTM D5183 "Coefficient of Friction of Lubricants" (ASTM International)

[4] ASTM D2783 "Extreme Pressure Properties of Lubricating Fluid" (ASTM International)

[5] ASTM D7217 "Extreme Pressure Properties of Solid Bonded Films Using an SRV Test Machine" (ASTM International)

[6] Hu, N., Zhang, X., Wang, X., Wu, N., & Wang, S. (2020). Study on Tribological Properties and Mechanisms of Different Morphology WS2 as Lubricant Additives. *MDPI*.

[7] Gulzar, M., Masjuki, H. H., Varman, M., Kalam, M. A., Mufti, R. A., Zulkifli, N. W. M., Yunus, R., & Zahid, R. (2015). Improving the AW/EP ability of chemically modified palm oil by adding CuO and MoS2 nanoparticles. *Elsevier*.

[8] ResearchGate. (n.d.). The Crystal Structure of Monolayer MoS2. researchgate.net. Retrieved October 22, 2021, from https://www.researchgate.net/figure/The-crystal-structure-of-monolayer-MoS2a-Coordination-environment-of-Mo-blue-sphere_fig1_225275198 .

[9] Ma, X., Gan, C., Li, X., Li, Y., Feng, P., Fan, X., Ye, X., & Zhu, M. (2021). Tribological Properties of SiO2@Cu and SiO2@MoS2 Core–Shell Microspheres as Lubricant Additives. Tribology Letters.