Tribological studies of multilayer and nanocomposite coatings

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By

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7. Conclusions and scope of future work.

This chapter unveils the key findings of the tribological study of multilayer and nanocomposite coatings. Finally, the chapter sums up the scope of future work for further studies.

7.1. Conclusions.

The dissertation work is focused on developing three different types of coatings (multilayer and nanocomposite) for different tribological applications:

1. A new multilayer Ti/TiN coating design was proposed and tested under reciprocating sliding conditions.
2. New multilayer coatings containing Mo/DLC were developed to enhance the galling resistance of SS 304 at elevated temperatures.
3. A cost-effective way to increase the galling resistance of SS 304 was explored at room temperature through PU-based nanocomposite coatings.

The Ti/TiN multilayer coatings showed a significant reduction in wear when tested in the presence of paraffin oil at elevated temperatures (100˚C). The new multilayer structure helped in depositing coating of higher thickness by reducing the internal stresses inside the coating. Also, the wear loss was almost negligible at 100˚C after 18000 cycles. This was attributed to the formation of the rutile phase of TiO_2, which was confirmed by the Raman spectroscopy results. In the absence of paraffin oil, the wear increased with increasing temperature. The Raman results showed the presence of TiO_2 even in the absence of paraffin oil, but the anatase phase of TiO_2 was formed. The rutile phases of TiO_2 are more stable than the anatase phase, resulting in lower wear loss. However, the reason behind the formation of the rutile phase in the presence of paraffin oil was not identified and it needs further research.

The use of Mo/DLC multilayer coatings to increase the galling resistance of the SS 304 at room and elevated temperatures (300˚C) opened new areas for improving the galling resistance of materials through PVD coatings. The DLC coating deposited through HiPIMS was dense and had a high percentage of sp^3 hybridized carbon. The higher the percentage of sp^3 carbon atoms in DLC, the higher is its thermal stability. A thick coating was achieved by incorporating soft Mo layers between the DLC layers. The incorporation of soft Mo layers helped reduce the internal stress (which is detrimental to the thick coatings above 1 µm) and also helped in lubrication at elevated temperatures by forming lubricious MoO_3 at 300˚C. The galling resistance of the coated on uncoated SS 304 tribopair was almost three times that of tribopair consisting of uncoated SS 304 only, at ambient and elevated temperatures.

The PU-based polymer coatings provided a cost-effective way to increase the galling resistance of SS 304 at ambient temperature. The reinforcement of the PU matrix with MoS_2 and MoS_2-ODT nanosheets showed significant improvement in its lubricating and antiwear properties. The reinforcement of PU with the nanosheets decreased its surface energy and increased the hardness and H/E ratio, which helped to improve the tribological properties. The MoS_2-ODT nanosheets had better dispersion in the PU matrix, and ODT's hydrophobic nature helped decrease the surface energy even more. Hence, the best tribological properties were obtained with the coatings reinforced with MoS_2-ODT nanosheets. The resistance of the PU-based nanocomposite coatings was better than the Mo/DLC multilayer coatings. It can be easily implemented in cold forging industries which do not operate at high loads and temperatures.

7.2. Scope of future work.

The limited application of lubricants and greases in harsh conditions has led to the development of coatings for various applications. While the world is moving into the era of space technology, hydrogen fuel cells, and electric vehicles, the focus has also shifted to sustainable and environmentally friendly products. Ceramic, DLC, and polymer-based coatings can be excellent alternatives to the toxic lubricants used in industries today. The present work has highlighted the potential of various coatings in reciprocating sliding and galling tests. The low film thickness of the ceramic coatings deposited through the PVD technique has also been addressed by inserting thin metal layers between the ceramic layers. However, there is still a large amount of work that can be done in the field of coatings:

- Since the current study was focused on coatings working in harsh environmental conditions, however, corrosion and tribo-corrosion studies can also be conducted on newly developed coatings.
- The HiPIMS deposits dense coating with no columnar structure. Therefore, other ceramic/metal combinations are required to be explored with HiPIMS to develop new coatings for various tribological applications.
- The present study establishes that the galling resistance can be improved using solid lubricant coatings on steel surfaces. Other solid lubricant coatings are also available commercially, which needs to be explored.
- Polymer coatings of PTFE, PEEK, PI, etc., which have high-temperature resistance, must be explored with different kinds of nano and micro fillers of SiO_2, Cu, CuO, glass fibers, etc., to increase the galling resistance at ambient and elevated temperature