Thermally Activated Adaptation in Tribological Coatings that Operate in Extreme Environments

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The focus of this work is to understand the mechanisms that lead to a reduction in friction and wear in high temperature adaptive materials. These materials include transition metal oxides and nitrides that are embedded with self-healing mobile phases that are thermally and/or mechanically activated to create easy-shear phases at sliding surfaces. Changes in the structural and chemical properties of these composite structures with temperature will be correlated to their performance using a range of experimental tools in addition to simulations based on *ab initio* and molecular dynamics calculations.

Keywords: self-healing, oxides, Raman spectroscopy

1. Introduction

Surface reconstruction/adaptation during sliding contact has received less attention so far but has the potential to create self-healing and self-lubricating materials that are crucial for environmentally friendly tribological applications. Friction and wear are usually viewed as irreversible processes that lead to energy dissipation (friction) and material deterioration (wear). These adverse effects can be mitigated using solid lubricants that are able to self-organize on sliding surfaces to minimize friction and/or wear. For example, ternary oxides were successfully incorporated into the design of adaptive coatings, whereby lubricious and hard phases are combined to form a composite material that reduces both friction and wear over a broad temperature range [1].

2. Methods

Bulk Nb_2O_5 cylinders were prepared by pressing Nb_2O_5 powders made of 5 µm average diameter particles (Sigma-Aldrich). The diameter of the cylinder before annealing was 12 mm. The Nb_2O_5 cylinders were sintered at 1300 °C for 3 h to minimize the open porosity and maximize strength. The post-sintering diameter of the cylinder was 9.65 mm.

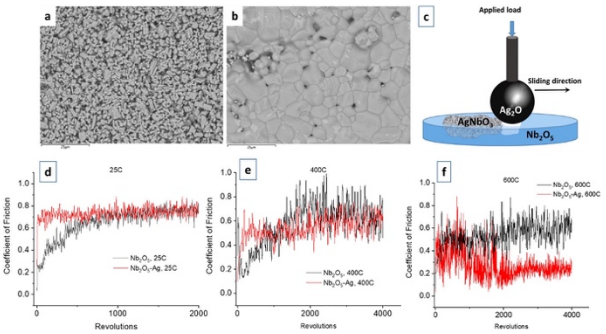

Fig. 1. Preparation of the bulk niobium oxide sample by (a) pressing and (b) sintering the pellet. The sample was further tested for the tribological performance (c). Tribology test of Nb_2O_5 with and without the presence of Ag at (d) 25 °C, (e) 400 °C and (f) 600 °C. Results indicate a reduction in the coefficient of friction in case of silver presence at 600 °C (f).

The tribological properties of the ceramics were tested using the Nanovea high-temperature macroscale pin-on-disk tribometer. The tests were performed at room temperature (~25 °C) and at elevated temperatures (~600 °C). In these tests, a flat niobium oxide samples were sliding against a silver coated (2.5 µm thickness) silicon nitride ball. The ball diameter was 6 mm. The tabulated tribology tests parameters are shown in Table 1. The normal load during the tests was kept at 1 N and a wear track of 4mm radius was used for each experiment. Sliding speed during the tests was 60 rpm (2.5 cm/s).

3. Discussion

The mechanism of lowering the high-temperature healing requirement by assisting the process of crack repair with a normal load and shear stresses to induce an adaptive tribochemical event between sliding surfaces was explored. For this, the material system consisting of niobium oxide and silver has been studied using macroscale pin-on disk tests. The selection of this particular sliding chemistry led to the formation of a lubricious ternary $AgNbO_3$ phase at the interface once the temperature reached ~ 600 °C. Interestingly, in the absence of sliding, the temperature needed for the ternary phase formation exceeds 945 °C. The observed formation of the ternary phase was accompanied by a three-fold decrease in the friction coefficient value as compared to niobium oxide/silicon nitride system. The enhanced tribo-performance was associated with a tribologically-activated surface reconstruction process initiated inside the wear track. The formation of the lubricious ternary oxide at a much lower than thermodynamically required temperature suggests that the self-healing process can be initiated with mechanically induced stresses. Such a process is a new recipe for improving wear and crack resistance characteristics of ceramic components and may be tuned to provide the desired frictional response.

4. References

[1] A. Shirani, J. Gu, B. Wei, J. Lee, S.M. Aouadi, D. Berman, "Tribologically enhanced self-healing of niobium oxide surfaces", Surf. Coat. Technol. 364 (2019) 273-278.