Comparison of WC/DLC/WS\textsubscript{2} and YSZ/Au/DLC/MoS\textsubscript{2} “Chameleon” Coatings for Tribological Applications

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ABSTRACT

Chameleon coatings are nanocomposite systems that adapt their tribological performance to changes in environmental conditions such as humidity and temperature. In this research we have investigated the tribological properties of two nanocomposite “chameleon” coatings and compared their properties. The two material systems of interest included: (i) Diamond like carbon (DLC) matrix with nanocrystalline WC and WS\textsubscript{2} inclusions, and (ii) Yttrium Stabilized Zirconia (YSZ) in an Au matrix with DLC and MoS\textsubscript{2} nanoparticle inclusions. The coating design approach included formation of nanocrystalline hard carbide or oxide particles for wear resistance, embedding them into an amorphous matrix for toughness enhancement, and inclusion of nanocrystalline and/or amorphous solid lubricants for friction adaptation to different environments. The coatings were produced using a combination of laser ablation and magnetron sputtering. Chemical and structural analysis of the coatings included x-ray photoelectron spectroscopy, x-ray diffraction, transmission electron microscopy, and micro-Raman spectroscopy. Mechanical properties such as coating hardness and toughness were investigated using nanoindentation, scratch, and indentation adhesion tests. It was observed that both YSZ and WC are valuable in enhancing film toughness. The chemical analysis was used to ascertain a correlation between chemical bonding of species and frictional properties. Friction measurements were studied by cycling between humid air and dry nitrogen conditions. The graphitic carbon component imparted low friction in humid air, MoS\textsubscript{2} and WS\textsubscript{2} were excellent for dry N\textsubscript{2} conditions, and Au was valuable for low friction at elevated temperatures. The direct comparison among coatings demonstrates that similar “chameleon” behavior can be achieved with different material systems, validating the universal nature of the design approach.

INTRODUCTION

A challenge in tribological coatings research is to obtain coatings with low coefficients of friction (c.o.f.) in a number of varying environmental conditions. This is especially important for aerospace applications. Satellites which are designed for high vacuum in space also need to be exposed to moisture during launch as well extreme temperature fluctuations. Solid lubricants that impart low friction behavior in one type of environment do not generally work well in another. In this case a composite coating which can adapt its behavior to the changes in condition is important.

We have previously reported on adaptive “chameleon” coatings where excellent tribological properties are achieved in varying environments.\textsuperscript{1,2} In fig. 1 a schematic of a chameleon coating is given. The coatings have various solid lubricant components that give low coefficients of friction in both humid environments and in vacuum or dry nitrogen. The coatings also have nanocrystalline ceramic or carbide phases that impart hardness and wear resistance. Here we compare the properties of two such chameleon coating systems WC/DLC/WS\textsubscript{2} and YSZ/Au/DLC/MoS\textsubscript{2}.

EXPERIMENTAL

WC/DLC/WS\textsubscript{2} and YSZ/Au/DLC/MoS\textsubscript{2} coatings were prepared in a vacuum chamber using magnetron assisted pulsed laser deposition (MSPLD). For the YSZ/Au/DLC/MoS\textsubscript{2} coatings, sectioned targets were used for laser ablation with quarter circles of YSZ, MoS\textsubscript{2}, and graphite, while Au was deposited using magnetron sputtering. For WC/DLC/WS\textsubscript{2}, a graphite target was used for laser ablation and a WS\textsubscript{2} target was used with magnetron sputtering. Graded layers were produced in each case to obtain good coating adhesion to the substrates. The samples were grown on various mirror polished 24.5 mm diameter substrates including 440c steel, 52100 steel, M50 steel, silicon, and inconel. The substrates were biased at 100V with respect to ground and heated to 200°C to promote coating crystallization.

The coefficient of friction was measured in samples using a ball on disc tribometer with M50 steel balls and a rotational speed of 200 rpm. The tests were run during cycling between air at 40% RH and nitrogen at <1% RH.
RESULTS AND DISCUSSION

From XPS analysis, a typical YSZ/Au/DLC/MoS$_2$ sample composition was 38 at. % YSZ, 30 at. % Au, 15 at. % MoS$_2$, and 20 at. % Carbon. The WC/DLC/WS$_2$ coatings had a typical composition of 20 at. % WS$_2$ and 60 at. % Carbon. The coatings were generally ~1 µm thick.

Tribological property comparisons between the coatings in both environments have shown that both systems give similar “chameleon” type behavior. In fig. 2 the coefficient of friction for up to 60,000 sliding cycles in a typical YSZ/Au/DLC/MoS$_2$ coating is given. The coefficient of friction is found to be ~0.02-0.03 in dry nitrogen and 0.1-0.2 in humid air. The systems have been found to exhibit these low friction properties to 50,000 sliding cycles or more.

The low friction coefficient for both coating systems in dry nitrogen is attributed to the dichalcogenide lubricants WS$_2$ and MoS$_2$. The lubrication mechanism begins with the transformation of amorphous or poorly crystalline WS$_2$ or MoS$_2$ phases into more developed hexagonal phases. Then a lubricating transfer film develops on the coating and ball counterface. This film is formed easily due to weak Van der Waals forces between hexagonal basal planes. The basal planes shear upon sliding contact. In high humidity environments, however, water adsorption can increase friction in dichalcogenides. This is where graphitic carbon takes over.

For the DLC phase, friction induces sp$^3$→sp$^2$ phase transitions, which then form a graphitic transfer film. Interplanar bonding in graphite is composed of weak sp$^2$ bonding as well as a contribution from stronger free sp$^3$ bonds. When condensable water vapor is present its molecules can bond with the free sp$^3$ bonds thus lowering their energy. The result is a lower c.o.f.

While gold was effective in lowering the c.o.f. at high temperatures for the YSZ/Au/DLC/MoS$_2$ composite, it may in fact lower the c.o.f. in dry nitrogen conditions as well, as has been previously reported. The mechanism for Au lubrication is the result of Au nanograin nucleation on the surface of the coatings which are then smeared during sliding. Further experiments will be performed to investigate whether composites with Au do indeed give lower c.o.f.

To conclude, we have synthesized two chameleon coatings and studied their tribological properties. Both coatings have been found to adapt their behavior to give a lower coefficient of friction in humid air and dry nitrogen.

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REFERENCES


