Hydrogen and Wear Resistant Nanolaminate Coatings

The use or intended use of hydrogen as an alternative fuel in the U.S. is growing rapidly but there are many challenges to the hydrogen economy, including hydrogen production, hydrogen transportation, and hydrogen infrastructure compatibility. Specifically, the use of metallic moving parts in hydrogen environments presents a range of technical problems that require properly designed wear-resistant coatings that are compatible with hydrogen gaseous environments. Low-friction coatings that are hard and durable in hydrogen do not currently exist but several nanolayered systems have great promise to provide the required protection. Nanolayered coatings, or nanolaminates, rely on proper design of layer spacing, crystal structure, and composition to achieve high hardness values, typical exceeding at least 10 GPa with peak hardness values exceeding 40 GPa in a well-designed system. These hardness values greatly exceed that of most hardened steels, which can be prone to hydrogen embrittlement. Nanolayered coatings, since they rely on completely different deformation mechanisms than steels to achieve high strength and hardness, are not expected to be sensitive to hydrogen degradation in the same manner. However, hydrogen can possibly chemically degrade coatings and diffuse beneath coatings to embrittle the underlying substrates. Therefore, a degree of permeation resistance may also be required.

This nanomanufacturing concept definition study will develop the concept of superhard coatings based on alternating nanoscale layers of sputter-deposited coatings with anticipated hydrogen compatibility and low friction coefficients. Films of metal carbides and metal nitrides with layer thicknesses in the range of 10nm or less will be deposited on a typical hardened steel substrate, such as M2 tool steel, with and without underlying bond coats to achieve a superhard surface with low friction and hydrogen compatibility. Reactive balanced and unbalanced magnetron sputtering will be used to fabricate these coating systems. Wear tests will be performed in situ in hydrogen for comparison with tests in air and in inert environments. Coating characterization will be performed using X-ray diffraction/reflectivity, X-ray photoelectron spectroscopy, Raman spectroscopy, electron microscopy, and AFM hardness testing. These coatings will be compared with diamond-like carbon coatings of similar thickness. There is little known regarding the compatibility of such superhard coatings in hydrogen so this will be the focus of this work and the main technical hurdle. Success with this approach will be significant since the continuing use of existing materials would be enabled with the addition of this coating technology, thus saving the cost of new structural materials development and allowing the use of hydrogen fuels in a wide range of applications.

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