Chapter 9
High Temperature Nanocomposite Coatings by Plasma Spraying for Friction and Wear Applications

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ABSTRACT

In conventional high temperature solid lubricants, during thermal cycling, a reduction of lubrication performance results in fluctuating friction coefficient and formation of abrasive wear debris. Moreover, the demand for high temperature solid lubrication in the range 300-1000 °C has led to development of self-lubricating wear resistant coatings of desired characteristics at high temperatures. This chapter introduces typical nanostructured ceramic matrix coatings produced by plasma spraying for self-lubricating wear resistance purposes in a wide temperature range. Production and properties of spray dried agglomerated nanocomposite granules are described and, then, structural, mechanical and tribological properties of Cr2O3-Ag nanocomposite coatings are presented. The lubrication mechanisms at moderate and high temperatures, by means of creation of a silver tribofilm on top surface, is discussed.

INTRODUCTION

There have been an increased interest in self-lubricating composite coatings in recent years for tribological applications at moderate to high temperatures. The most notably is adaptive and chameleon coatings produced by such processes as magnetron sputtering, chemical vapor deposition and hybrid vacuum arc, magnetron sputtering, pulsed laser deposition techniques (Donnet, & Erdemir, 2004; Muratore, Hu, Voevodin, 2009), PS series coatings produced by plasma spraying (Sliney, 1979) and laser surface modified adaptive coatings (Voevodin, & Zabinski, 2006). Solid lubricants include graphite, MoS2, PTFE
and fluorides, and there is an increasing demand for self-lubricating wear resistant coatings that can accomplish the required lubrication at different environments as well as long wear endurance, mainly for bearings and other mechanical components in aerospace industries. Nevertheless, temperature range for conventional monolithic solid lubricants is particularly difficult to extend; their effective operation is limited to 250-400°C in air, above which the material is oxidized or decomposed, leading to loss of lubricious nature (Erdemir, 2001; Sliney, 2001). Self-lubricating wear resistant coatings contain several phases in a composite structure to accomplish the required lubrication. The example of these coatings are Ag/BaF\(_2\)-CaF\(_2\) in Cr\(_2\)O\(_3\) (Kim, Choi, Han, Uhm, & Lee, 2005), Ag in CrN (Mulligan, & Gall, 2005), MoS\(_2\)/Ag in Mo\(_2\)N (Aouadi et al., 2009) and adaptive coatings that can be operated over a wide range of working environments (Muratore, Hu, & Voevodin, 2009).

One successful approach to development of self-lubricating composite coatings with various environment operation is using solid lubricant interactions with environments to generate a low shear interface between the matrix and the wear counterpart, as self-lubricating contact surface, for various ambient conditions. Moreover, the high hardness of matrix combined with low friction of reinforcement gives very low wear rates and mechanical properties of the coatings; these characteristics coupled with good adhesion lead to high load-bearing capacity.

A number of hard coatings containing gold and silver, as solid lubricant particles, have been investigated (Aouadi et al., 2008; Mulligan, & Gall 2005). Soft metallic lubricants have multiple planes in crystal structures, thereby, do not work harden significantly during sliding. Silver is chemically inert and has a low shear strength even below 300°C. During operation of such coatings, a thin lubricant Ag layer forms on the top surface; this soft-on-hard coating approach will avoid the high wear rate that would be observed in a pure silver layer. In addition, the hard coating avoids plastic deformation on consequent irregular surface morphologies that are common for pure soft coatings. A common disadvantage of the noble-metal based lubrication coatings produced is a lack of reversibility of the surface adaptations when subjected to temperature cycling (Mulligan Blanchet, & Gall, 2010).

Since crystalline solid lubricants are typically very soft and cause a significant reduction in hardness and elastic modulus of composite structure, amorphous and poorly crystalline nanoparticle inclusions with minimum detrimental mechanical effects were introduced in self-lubricating composite coatings. Such coatings have been developed generally in PVD processes but rarely considered in thermal spraying techniques.

Plasma spray process is an appropriate industrial method in order to fabricate self-lubricant wear resistant composite coatings. An essential point of the quality criteria is the homogenous distribution of reinforcements in the matrix. For this reason, the production of composite powders by spray-drying agglomeration procedure to fabricate thermal sprayed coatings is increasing.

Plasma sprayed nanocomposite ceramic matrix coatings may be employed for improved toughness, wear and friction properties over a wide range of temperatures; these properties are often provided by nanostructural semi-molten zones that reduce lamella thickness and increase crack propagation resistance. The key to good performance appears to be the avoidance of fully nanostructural features, rather, an essential point of the quality criteria is to produce a homogenous distribution of reinforcement and semi-molten nanostructured zones in the matrix of coating.

Several studies have focused on improvement of toughness and reduction of friction coefficient of Cr\(_2\)O\(_3\) coatings, achieved by structural modification procedures. One of the recent methods is the double glow-discharge plasma technique combined chromizing and plasma oxidizing treatments (Liu, Tao, Xu, Chen, & Gao, 2009). Another one is production of plasma sprayed nanostructured Cr\(_2\)O\(_3\) coatings (Cel-