Particulate-Reinforced Metal Matrix Composites

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Particulate-reinforced metal matrix composites (PRMMCs) with excellent tribo-mechanical properties are important engineering materials and have attracted constant scientific interest over the years. Among the various fabrication methods used, co-electrodeposition (CED) is valued due to its efficiency, accuracy, and affordability. However, the way this easy-to-perform process is carried out is inconsistent, with researchers using different methods for volume fraction measurement and tribo-mechanical testing, as well as failing to carry out proper interface characterization.

Keywords: experimental mechanics ; tribology ; co-electrodeposited composites ; interface characterization ; metal matrix composite ; ni-based composite ; electrodeposition

1. Introduction

Composites are materials that combine two or more phases: a continuous one, denoted as a matrix, and an embedded, discontinuous reinforcement. Such structures are preferably used to improve on certain properties of single constituents. For example, one can tailor composites' tribo-mechanical and physical properties to meet many different and sophisticated application requirements. Furthermore, due to the fact that they can be produced as coatings, it is possible to significantly reduce the cost of application. It should be noted that the technique of surface coating allows the use of cheap, low-quality substrate while still providing a surface with a suitable performance, especially in terms of tribo-mechanical properties. In composite coatings, a matrix can be built from a polymer, ceramic, or metal. Metal matrices are used when elevated temperatures are expected (and thermo-plastic polymers could not suffice) or when ductility is required (and brittle ceramic could not suffice). Ceramic reinforcements are often used, with the most common being Al_2O_3 and SiC. Particulate-reinforced metal matrix composites (PRMMCs) are of significant interest due to their lower cost and easier route of processing than fiber-reinforced MMCs. Among the many fabrication techniques used for MMCs [1], co-electrodeposition (CED) provides wide tailoring range yet remains affordable, with repeatable results applicable for complex geometries [2]. Co-electrodeposition means the electrodeposition of a metal coating on a substrate while embedding a reinforcement. Basic types of structures that can be obtained with CED are single-metal, alloy, or multilayer deposits with (nano-)particles, (nano-)wires, or nano-tubes. The deposition can be conducted under direct current (DC), pulsed direct/reverse current PDC/PRC), potentiostatic mode (P), or pulsed potentiostatic mode (PP). Furthermore, there is increasing interest in hybrid composites which are fabricated simultaneously with more than one type of reinforcement [3].

2. Future Outlook

The thorough study of the tribo-mechanical parameters of Ni-based CED PRMMCs with an interfacial standpoint has made some key findings, as listed below. The various CED fabrication details used cause many inconsistencies throughout papers. Despite the numerous investigations, the influence of a reinforcement on the composite properties is not clear—the presence of particles changes the microstructure of the matrix, therefore a simple comparison of electrodeposited Ni and co-electrodeposited Ni–SiC composite (with the same process parameters), is not enough for insightful study. The use of a wide range of available particle sizes and testing methods causes difficulties in drawing general conclusions. For wear rate, we introduced normalized wear rate as a ratio of the wear parameter reported in a given work to the wear parameter in that work measured for the lowest reinforcement vol.% (usually 0%). This showed that wear rates tend to have a minimum, however studies that use a wider range of reinforcement vol. % are needed. Additionally, it can be tentatively argued that the higher the vol.% for the minimum wear rate is, the stronger the matrix–reinforcement interface is. For hardness tests, usually there is a deficiency in basic parameters—the size of indentation imprints and their spacing are crucial for a proper analysis of the results concerning the size of particles. The maximal load chosen should be small enough to exhibit an indentation depth of less than 10% of the coating thickness and big enough to enable averaging over a representative volume element. AFM or OM images of the indent could be also of significant value for results analysis. Additionally, 3D-tomography or cross-sectional indentation could lead to insightful observations where interfacial strength plays a crucial role in the material behavior. For friction tests, sample preparation should be given more attention. The roughness of the CED composite would be high due to the loose attachment of the reinforcement at the surface layer. Without proper polishing prior to a friction test, reinforcement particles can detach, form a hard third body, and increase the friction. Additionally, the stronger the interface, the higher the load to be transferred via reinforcement and supposedly the lower the CoF. Statistical models were proven to be of significant value and should be employed in investigations where several parameters are investigated. Despite the establishment of direct interfacial strength measurements, there is still a need to broaden and deepen the scope of such measurements. Firstly, this would allow us to study the mechanisms of deformation. Secondly, this would allow us to compare different manufacturing routes and optimize the properties of composites.

References

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