Atmospheric plasma spraying (APS) is a most versatile thermal spray method for depositing alumina (Al₂O₃) coatings, and detonation gun (D-gun) spraying is an alternative thermal spray technology for depositing such coatings with extremely good wear characteristics. The present study is aimed at comparing the characteristics of Al₂O₃ coatings deposited using the above techniques by using Taguchi experimental design. Alumina coating experiments were conducted using a Taguchi fractional-factorial (L₈) design parametric study to optimize the spray process parameters for both APS and D-gun. The Taguchi design evaluated the effect of four APS and D-gun spray variables on the measured coating attributes. The coating qualities evaluated were surface roughness, porosity, microhardness, abrasion, and sliding wear. The results show that the coating quality is directly related to the corresponding coating microstructure, which is significantly influenced by the spray parameters employed. Though it is evident that the D-gun-sprayed coatings consistently exhibit dense and uniform microstructure, higher hardness, and superior tribological performance, the attainment of suitable plasma-sprayed coatings can be improved by employing the Taguchi analysis.

Keywords: abrasion, alumina coating, design of experiments, D-gun coatings, DOE, optimization, plasma spray coatings, sliding wear, Taguchi analysis

1. Introduction

The application areas of plasma-sprayed alumina (Al₂O₃) coatings have grown, particularly in the field of combating wear.[1–4] Although it is widely recognized that APS of Al₂O₃ coatings can provide solutions to engineering problems, its ability to satisfy the requirements where high wear resistance is of great importance has to be raised. On the other hand, D-gun spraying is another promising thermal spray technology for depositing such coatings with extremely good wear characteristics.[5,6,7] However, the literature reveals that there have been very few studies ascertaining the relative performance of plasma- and D-gun-sprayed coatings.[6,7,8]

Exploitation of any coating system will lie in the generation and acceptance of appropriate quality assurance, i.e., a repeatable achievement of high-quality coatings. Hence, it is necessary to characterize, fully understand, and interpret the performance of such coatings. For most thermal spray processes, the optimization of the spray parameters is not a trivial task. This is primarily due to the large number of processing parameters or factors involved. Design of experiments (DOE) is an effective method for conducting experiments to enhance thermal spray coating properties through producing optimum values of spray parameters. A DOE only leads to correlations, not physical understanding.

Taguchi-type fractional-factorial designs are an efficient means of determining the effects of process parameters on the measured responses. They are easy to plan and readily adaptable to both continuous factors (i.e., those which are controllable at preset values) and discrete factors (i.e., those which are orderable but not measurable). Major advantages of using Taguchi methods include the ability to separate the effect of various factors that may have similar behavior and the ability to determine the effect of a factor whose magnitude may have the same order of magnitude as the error terms. Recently, plasma and high velocity oxy-fuel spray parameters have been successfully optimized using DOE techniques,[9–12] particularly the Taguchi method, but no such optimization studies have been carried out for the D-gun spray process.

2. Experimental Details

2.1 Description of the Taguchi Method

A Taguchi-style[13,14] design of experiment, i.e., L₈(2⁴⁻¹)-eight run, fractional-factorial, studying four process parameters, each at two levels, was employed to study the effect of selected process parameters on the quantitatively measured coating attributes. Prior experience helped the authors to identify the major process parameters and their operational ranges in the APS and D-gun spray process. Care was taken to avoid overwhelming the matrix by one parameter being unusually broader than the others. The main process parameters selected for the APS processes were primary gas flow, plasma arc current, powder feed rate, and...
spray distance. In the case of the D-gun process, fuel ratio, i.e., acetylene to oxygen ratio (C\textsubscript{2}H\textsubscript{2}/O\textsubscript{2}), carrier gas flow rate, frequency of detonations, and spray distance were the main process parameters. Each parameter has two levels, selected to vary around the standard settings. The natural and coded values of the main variables are given in Tables 1 and 2 for the APS and D-gun processes, respectively. Coating experiments PA01 through PA09 and DA01 through DA09 representing the eight runs evaluated (including the standard settings) with the Taguchi (L\textsubscript{8}) approach are shown in Tables 3 and 4 for APS and D-gun spray processes, respectively. The experimental runs of a given design were performed in a random order to reduce the influence of potential systematic errors.

After the experiments were conducted per the designed factors, the data were obtained for the coating attributes, viz., surface roughness, porosity, microhardness, abrasion, and sliding wear. The experimental data was subjected to multiple regression analysis and analysis of variance (ANOVA) for each specific coating attribute to select the significant level of the process parameter and to understand the magnitude of influence that each variable had on the coating properties. From the ANOVA calculations, rho percent contribution or rho percent (\(\rho\%\)) was calculated. The \(\rho\) value indicates the influence of the process parameter on the measured coating attribute, with a larger value indicating stronger influence. The description of statistical terms used in this study, as well as their analyses, is found in Ref 13 to 15. The Taguchi analysis was accomplished with GWBASIC programs.

### 2.2 Substrate and Coating Materials

Mild steel (0.25%C, 0.7%Mn, 0.25%Si, and 0.05%S) substrates were employed throughout for coating deposition. Samples with the following dimensions were used to prepare coated specimens for different wear tests.

- Abrasion wear: 75 × 25 × 15 mm.
- Sliding wear: pin—6 mm diameter, 30 mm length.

### 2.3 Precoating Substrate Preparation

Prior to coating by both APS and D-gun processes, the substrates were roughened by air blasting using alumina grit of ~60 mesh. The blasting was performed at an air pressure of approximately 0.5 MPa. Subsequent to grit blasting, the samples were ultrasonically cleaned.

### 2.4 Powder Characterization

Particle size analysis of the spray-grade powder was performed (illustrated in Table 5) using a laser particle size analyzer CILAS 920 (Cilas Le Sens de la Mesure, Marcoussis, France). The powder particle size determined from the analysis generally conforms to the data given by the manufacturer. Scanning electron microscopy (SEM) was used to observe the morphology of the powder.

### 2.5 Deposition of Alumina Coatings

Plasma spray deposition of Al\textsubscript{2}O\textsubscript{3} powder was performed using a Metco 7MB APS unit. The spray parameters employed...