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ScienceDirect
Journal of Magnesium and Alloys 000 (2018) 1–9
www.elsevier.com/locate/jma

Full Length Article

Optimization of PVD process parameter for coating AZ91D magnesium alloy by Taguchi grey approach

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Received 14 December 2016; received in revised form 9 February 2018; accepted 27 February 2018
Available online xxx

Abstract

This study was an attempt made to explore the possibility of increasing the surface properties of the AZ91D magnesium alloy by applying ZrO_2 coating using Physical Vapour Deposition (PVD-RF) sputtering process. In order to improve the quality of the coating, the PVD process parameter with multiple performance characteristics was optimized by using the Taguchi grey approach. L_{18} orthogonal array was selected for conducting the experiments. The proposed Taguchi grey method was find out the optimal process parameter for multiple performance characteristics. The optimal combination was attained at chamber pressure of 0.003 bar, argon gas in millibar and power input of 200 W. The validation experiment result shows an improvement in the micro hardness and surface finish. Also, the performance characterizations such as SEM, EDX, XRD, coating thickness, surface roughness and micro hardness were measured at optimal process parameter.

Keyword: PVD coating; Mg alloy; Taguchi grey approach.

1. Introduction

Magnesium alloys have better mechanical properties with light weight, this make an advantage to use in the automotive and aerospace sectors [1] and for most of the environmental exposed applications; it is significant to modify the surface properties of the Mg alloys. The AZ91D Mg alloy is commonly used in automotive applications because of its excellent cast-ability performance. However casting defects such as porosity, shrinkage may occur [2]. Numerous methods of surface treatments are applied to enhance the surface properties of the material [3,4]. In this, coatings have recently considered highly because of the possibilities of developing materials with better surface properties [5]. The ceramic coatings are widely applied on alloys to improve their surface properties. Ceramic coatings applied by thermal spraying techniques such as physical vapour deposition, chemical vapour deposition, plasma spray etc. brings better diffusion and defect free surface [6]. The ceramic oxide coated materials are free from chemical inertness and shows high thermal stability properties rather than non-oxide coatings [7]. The stabilized zirconium dioxide ceramic coating material exhibits a high hardness, thermal, corrosion and wear resistance properties and are being used in high temperature coating for industrial applications [8].

The PVD coating improves the hardness and wear resistance of the material and this process is more environmental friendly than conventional coating process. Coating process parameter optimization is necessary to study the significance of the parameter that influences the coating performance. The PVD process parameters play an important role on the resultant coating performance such as coating hardness, roughness [9–11].

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https://doi.org/10.1016/j.jma.2018.02.004

A statistical approach like the Taguchi method is employed for designing an experiment to minimize the number of experiments. The Taguchi method is not produce precise and quality optimization for a multi performance problem [12]. However, Grey relational analysis proposed by Deng [13] is applicable to solve the multi performance problems. Sahoo et al. [14] used Taguchi based grey relational method to achieve the optimal tribological parameters (combination of load, speed and time) and which resulted in lower the coefficient of friction and wear of electroless Ni–B coating. Also this reveals that all the three parameters plays important role in friction and wear behaviour on coating. Taguchi design was adopted for conducting the experiment and to optimize the factors which attain higher metal transfer rate and surface finish in mild steel by electric discharge coating [15]. The tribological property on aluminium composites were investigated by grey relation analysis and in that the parameters such as load, sliding velocity, wt% of B_4C were optimized to obtain minimum wear rate and coefficient of friction [16]. Panja et al. [17] optimized the electroless coating process parameters using Taguchi based grey approach for deposit Ni-P on mild steel alloy.

Prasanta et al. [18] applied the grey relation analysis with weighted principal part analysis for locating out the optimal process parameters of electroless Ni-P-Cu coatings for better tribological properties and the confirmation result shows some improvement on the properties. Prasanta et al. [19] attempted to reduce the friction and wear performance by optimizing the chemical bath composition of electroless Ni-B coating using the Taguchi grey relation analysis. Yang and Huang [20] proposed a method that optimizes the multi-performance properties of zirconium coating on steel by an unbalanced magnetron sputtering process using Grey–Fuzzy Taguchi method. In this the following process parameters bias voltage, target current, pulse frequency, gas flow rate and work distance were considered for the optimization process and the results revealed that in optimal condition the friction coefficient and wear rate decreases.

From literatures, it was observed that no work have been discussed the effect of parameters on PVD coating and their influences. The objective of this investigation was to obtain an optimal PVD-RF sputtering process parameter to get quality performance characterizations. Further, the validation test was conducted at the optimal condition with the following performance characterizations such as SEM, XRD, coating thickness, surface roughness and microhardness were measured.

2. Multi objective Taguchi based grey relation optimization theory

Optimization of process parameters using a minimum number of experiments by adopting the Taguchi grey method gives high quality result [21,22]. In Taguchi method, the S/N ratio is used to calculate the deviation between the measured value and the desired value. For this S/N ratio calculation, a loss function can be transformed into S/N ratio. Usually, this loss functions are divided into three categories namely lower the better, higher the better and nominal the best [23].

In this study, lower the better and higher the better are preferred to determine the desired value. The loss function for the lower the better characteristic can be expressed as

$$L_{ij} = 1/n\Sigma {y_{ij}}^2 \tag{1}$$

The loss function for the higher-the-better characteristic can be expressed as

$$L_{ij} = \frac{1}{n}\sum_{k=1}^{n}\frac{1}{yij\ \ 2} \tag{2}$$

$$\eta_{ij} = -10\ log(L_{ij}) \tag{3}$$

where, L_{ij} is the loss function of the ith performance characteristic in the jth experiment, y_{ijk} is the experimental value of the ith performance characteristic in the jth experiment at the kth trial, and n is the number of trials.

Moreover, the Taguchi method is a single response characteristic optimization approach. Therefore multi performance approach such as grey relation grade is considered to solve this problem. The objective of the grey relation analysis is used to find out the parameters that give better performance [24,25].

In the grey relation analysis, the normalization process is essential because the high deviations in S/N ratio are converted into dimensionless as zero and unity by Eq. (4). Secondly, this normalized S/N ratio is converted into grey relation coefficient using Eq. (5) which represents the correlation between the required and actual S/N quantitative relation. Then by Eq. (6) the grey relation grade is calculated by averaging the grey relation constant. Thus the multiple performance response can be converted into a single grey relation grade.

The normalized S/N ratio χ_{ij} for the ith performance characteristic in the jth experiment can be expressed as

$$\chi_{ij} = \frac{\eta_{ij} - \min\eta_{ij}}{\max\eta_{ij} - \min\eta_{ij}} \tag{4}$$

where χ_{ij} is the value after the grey relational generation, min η_{ij} is the smallest value η_{ji} of the jth response, and max η_{ij} is the largest value of η_{ij} for the jth response.

The grey relational coefficient ζ_{ij} for the jth performance characteristic in the jth experiment can be expressed as

$$\zeta_{ij} = \frac{\min_i\min_j\left|\chi_i^0 - \chi_{ij}\right| + \zeta\max_i\max_j\left|\chi_i^0 - \chi_{ij}\right|}{\left|\chi_i^0 - \chi_{ij}\right| + \zeta\max_i\max_j\left|\chi_i^0 - \chi_{ij}\right|} \tag{5}$$

The grey relational grade γ_j can be obtained

$$\gamma_j = \frac{1}{m}\sum_{k=1}^{n} w_i\zeta_{ij} \tag{6}$$

where γ_j is the grey relational grade for the jth experiment, w_i the weighting factor for the ith performance characteristic, and m is the number of performance characteristics.

Please cite this article as: M. Sivapragash et al., Optimization of PVD process parameter for coating AZ91D magnesium alloy by Taguchi grey approach, Journal of Magnesium and Alloys (2018), https://doi.org/10.1016/j.jma.2018.02.004