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Abrasion wear of HVOF sprayed coatings on SUS 400 stainless steel

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Abstract

This research diagnoses the optimization parameters for minimum mass loss of abrasive wear testing on SUS 400 stainless steel by design of experiment (DOE). In experimental, two input parameters that were the type of HVOF sprayed coating (i.e. CrC-NiCr and WC-12Co) and the testing distance (i.e. 3000m, 6000m, 9000m, 12000m, 15000m, 18000m, 21000m, 24000m, 27000m, and 30000m). Factorial experiment technique of DOE was used the MINITAB software for designing and analyzing of optimized parameters. The influences of two parameters on mass loss were investigated using analysis of variance (ANOVA) at 95% confidence level. The main effect and interaction of two parameters were significantly affect the mass loss. The statistical results of HVOF sprayed coating were indicated the WC-12Co better abrasive wear resistance than the CrC-NiCr.

Keywords: Abrasive Wear, High Velocity Oxygen Fuel (HVOF), Factorial Experiment, Analysis of Variance (ANOVA).

INTRODUCTION

The abrasion wear was the main failure of several mechanical parts in many industrial fields. In application of wear resistance, the coatings commonly prepare the prevention to wear. The high velocity oxy-fuel (HVOF) spraying was accepted by industries as one of the best methods to modify the good quality of mechanical property [1]. HVOF was used to apply deposition wear resistance on substrates of various industries namely; automotive, aerospace, and electronics [2]. In the past, researchers were studied the HVOF application to improve the wear resistance. Wang et al. [3] have described the abrasive wear resistances of WC-12Co by HVOF coatings that the multimodal coating shows slight higher microhardness and better abrasive wear resistance than the conventional counterpart. Also, the thermally sprayed carbide-based coatings have excellent wear resistance with respect to the hard chrome coatings. Mindivan et al. [4] have explained the wear resistance testing of the HVOF sprayed WC-12Co+6% ETFE coatings on AA2024-T6 aluminum alloy that the plasma sprayed WC-12Co+6% ETFE coating tested in acid environment exhibited a lower wear resistance when compared to the result of the experiment performed on dry sliding condition. Oladijo et al. [5] have studied the 3 body abrasion wear characterized of HVOF WC-17 wt% Co coating by ASTM-G65 tester. Summary, the coatings deposited onto brass shown compressive stresses while those deposited onto super-invar had tensile stresses, yet these two coatings had similar wear rates. Maranho et al. [6] have investigated the effects of two substrate types namely; substrate of pre-heating and substrate of heat treatment coating on mass loss by ASTM G65. The results were indicated the mass loss of substrate of heat treatment coating lower than substrate of pre-heating.

Studying the influence of HVOF spray parameters using design and analysis of experiments (DOE). The DOE was allowed the investigation of the main effects and interaction effects among parameters. This principle has been proved by several researchers. Wang et al. [7] have described the parameters optimization and abrasion wear mechanism of liquid fuel HVOF sprayed bimodal WC-12Co coating. The result of Taguchi experiment were exhibited the excellent performance of bimodal coating deposited under the optimal spray parameter, which can be attributed to its small mean free path of the cobalt binder resulting from the bimodal distribution of WC particles. Murugan et al. [8] have studies the optimum HVOF spray parameters to attain minimum porosity and maximum hardness in WC–10Co–4Cr coating sprayed on naval brass substrate. From the statistical results of design of experiments (DOE) and response surface methodology (RSM), they were indicated that the oxygen flow rate has greater influence on coating porosity and hardness followed by LPG flow rate, powder feed rate and spray distance, respectively. Zoei et al. [9] have investigated the influence of grinding parameters (e.g. cutting speed, feed rate, and depth of cut) on the wear resistance and the residual stress of WC–10Co–4Cr coating by HVOF. The results exhibited that the higher value of compressive residual stress, which is caused by the increase of the depth of cut and feed rate and the decrease of the cutting speed, improves the wear resistance of the coating.

Therefore, this present study was carried out with proper to compare the relationships to define the minimum mass loss of HVOF sprayed CrC-NiCr and WC-12Co coatings on SUS 400 stainless steel substrates. The factorial experiment was performed to optimize the parameters to obtain minimum mass loss.

EXPERIMENTAL PROCEDURE

In this research, the wear resistance testing under ASTM G65 standard was performed to analysis the wear characteristics of HVOF sprayed CrC-NiCr and WC-12Co coatings on SUS 400 stainless steel substrates. The SUS 400 stainless steel of size 25mmx50mmx5mm were used as a substrate materials for abrasion wear test. The similar HVOF-parameters of two coatings were shown in Table 1, which were coated the substrates by SULZER METCO DIAMOND JET machine.

The substrate thickness of coating film were measured of 350 µm by stylus profiler. The substrates were tested with abrasion tester by ASTM G65 standard (as shown in Fig. 1). The speed of wheel covered by rubber was 240 rpm and rotate against with substrate under applied load of 30 N.

Table 1. The HVOF-parameters of CrC-NiCr and WC-12Co coatings.

Ratio of oxygen pressure	270	L/min
Ratio of propane	17.5	L/min
Feed rate powder	116	g/min
Coating distance	250	mm
Coating temperature	3000	ºC

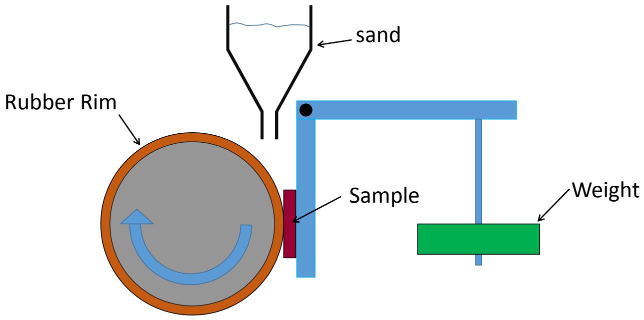

Figure 1. Schematic diagram of the abrasion tester (ASTM G65).

The factorial experiment were involved 60 testing at two input variables namely; type of coating (CrC-NiCr and WC-12Co), and testing distance (e.g. 3000m, 6000m, 9000m, 12000m, 15000m, 18000m, 21000m, 24000m, 27000m, and 30000m). The data of factorial experiment table in this research was given in Table 2, which was created from MINITAB software.

Table 2. The mass loss data of factorial experiment for analysis of variance (ANOVA).

Type of coating	Distance (m)	Mass loss (g)		
		1	2	3
CrC-NiCr	3000	0.072	0.074	0.073
(AST 914)	6000	0.145	0.162	0.170
	9000	0.231	0.250	0.258
	12000	0.313	0.329	0.334
	15000	0.392	0.414	0.421
	18000	0.475	0.497	0.503
	21000	0.555	0.578	0.584
	24000	0.632	0.658	0.665
	27000	0.712	0.733	0.738
	30000	0.793	0.823	0.827
WC-12Co	3000	0.045	0.046	0.043
(AST 915)	6000	0.091	0.109	0.113
	9000	0.150	0.169	0.172
	12000	0.205	0.225	0.234
	15000	0.257	0.279	0.281
	18000	0.313	0.336	0.341
	21000	0.366	0.386	0.391
	24000	0.416	0.442	0.449
	27000	0.469	0.496	0.496
	30000	0.523	0.552	0.555

RESULTS

The statistical results have been subjected to analysis of variance (ANOVA) to evaluate the effect of control factors (testing parameters) on mass loss. This ANOVA result was done for a significance level of 0.05 (α), i.e., for a confidence level of 95%, which shown that the main effect (e.g. type of coating, and distance testing) and interaction effect were the most significant factor (see in the Table 3). Because, the probability of 95% confidence (p-value) of 0.05 was more than the probability of experiment (p-value) of 0.001, which exhibited model term was significant. Moreover, the R^2 coefficient of integrity of experiment data was estimated the R^2 of 99.71%

Table 3. The ANOVA results of mass loss.

Term	Sum of squares	df	Mean square	*F*-value	*p*-value
Model	2.73670	19	0.144037	732.89	< 0.0001
Type of coating	0.33168	1	0.331675	1687.63	< 0.0001
Distance (m)	2.31537	9	0.257264	1309.01	< 0.0001
Type of coating * Distance (m)	0.08965	9	0.009961	50.68	< 0.0001
Pure Error	0.00786	40	0.000197		
Total	2.74456	59			

The main effects plot of mass loss according to the factorial experiment analysis were shown in Fig. 2. With the increase of distance testing, the mass loss was increased. The tendency of distance testing parameter was linear relationship. Consideration of type of coating on mass loss, the WC-12Co film was less than CrC-NiCr film. Thus, the WC-12Co film has been the wear resistance more than CrC-NiCr film.

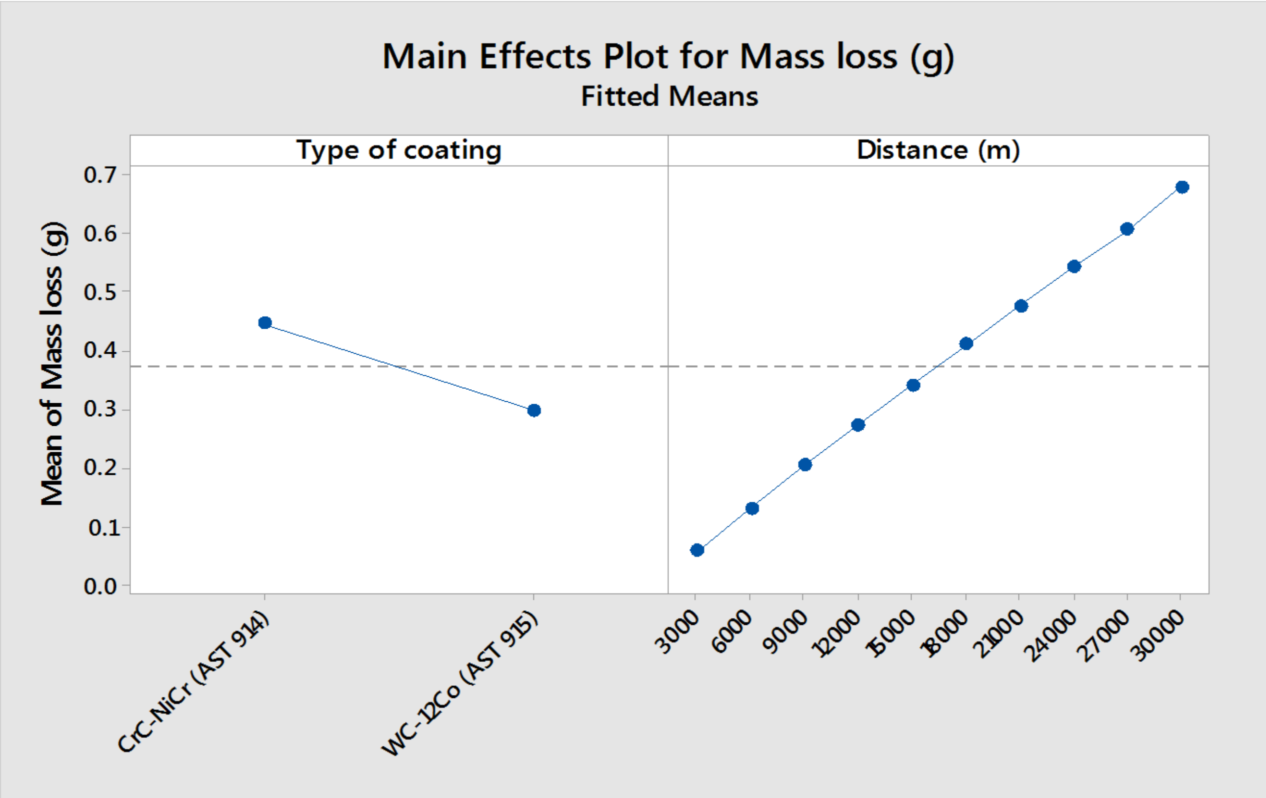

Figure 2. Main effects plot of mass loss.

The optimization plot followed by the type of coating (WC-12Co) and distance testing (3000 m) for obtaining optimum minimum mass loss as shown in Fig. 3. Therefore, these condition can be created that the minimum mass loss of 0.0447 g and the composite desirability of 99.787%.

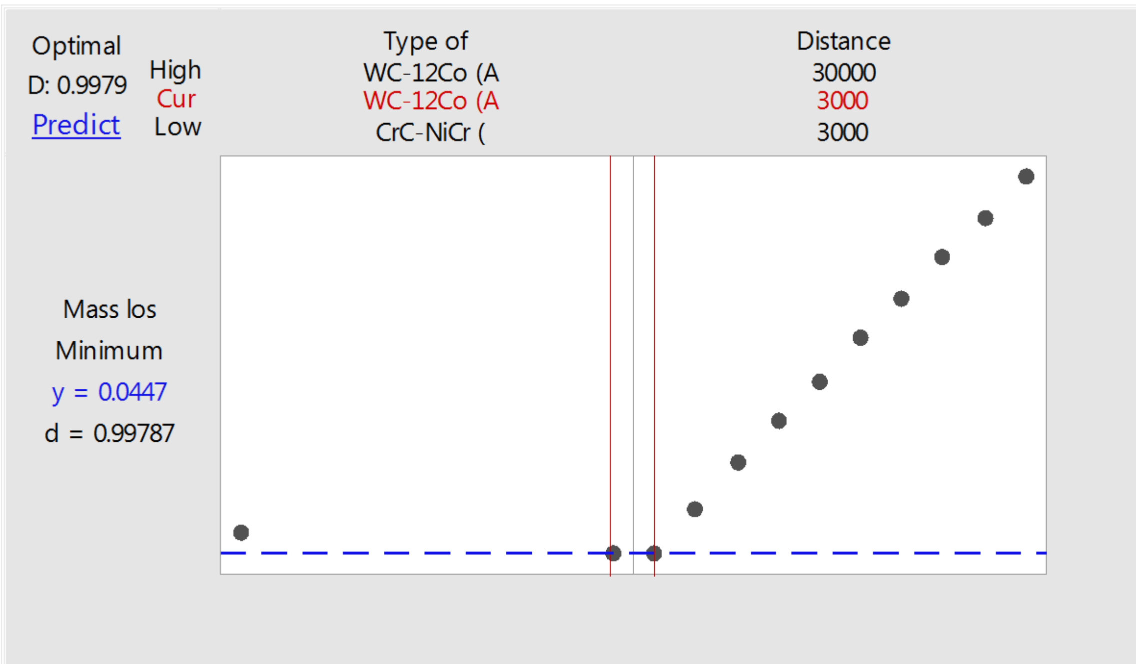

Figure 3. Optimization plots of minimum mass loss.

CONCLUSION

In this research, it can be concluded that the ANOVA results exhibits that the type of coating and distance testing were significant parameter on mass loss for a confidence level of 95%. The optimization condition, use the type of coating (WC-12Co), and distance testing (3000 m) to obtained better minimum mass loss.

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