International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:8, No:12, 2014

The Effect of Impinging WC-12Co Particles Temperature on Thickness of HVOF Thermally Sprayed Coatings

M. Jalali Azizpour, H. Mohammadi Majd

Abstract**—**In this paper, the effect of WC-12Co particle temperature in HVOF thermal spraying process on the coating thickness has been studied. The statistical results show that the spray distance and oxygen-to-fuel ratio are effective factors on particle characterization and thickness of HVOF thermal spraying coatings. Spray Watch diagnostic system, scanning electron microscopy (SEM), X-ray diffraction and thickness measuring system were used for this purpose.

Keywords**—**HVOF, Temperature, Thickness, Velocity, WC-12Co.

I. Introduction

BOND strength, stress distribution, compressive nature of residual stresses as well as the fatigue behavior of the coatings could be considered as the outlined features of HVOF coatings [1]-[3]. Mechanical, metallurgical and tribological properties of the coatings strongly influenced by the independent (primary)variables (the spray distance, oxygen to fuel ratio, powder feed rate, etc.) and related (secondary) parameters such as velocity and temperature of particles at the impact [4]-[7]. The ultrasonic particles velocities in HVOF thermal spraying process can produce compressive residual stresses hence improve mechanical properties such as fatigue life and bonding strength [8], [9]. Due to high cost WC-Co powder, it is important for industry to achieve deposition efficiency more than 60 percent.

In HVOF thermal spray process (Fig. 1) Molten or semi-molten materials are sprayed onto the surface by means of the high temperature, high velocity gas stream, producing a dense spray coating which can be ground to a very high surface finish.

Genichi Taguchi, Japanese engineer and statistician began formulating the Taguchi Method while developing a telephone-switching system for Electrical Communication Laboratory, a Japanese company, in the 1950s. As a result of his success, he eventually became well-known in both Japan and the United States, with companies such as Toyota, Ford, Boeing and Xerox adopting his methods.

In this study the effect of thermal spraying process parameters on particle temperature and thickness of WC-12Co coating on AISI1045 substrate has been investigated. Effect of the most important parameters such as spraying distance, the oxygen to fuel ratio, feed rate and gun speed was analyzed statistically using Taguchi approach. The standard array L9 was used to design of the experiments.

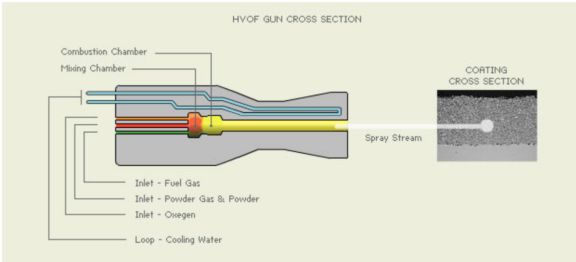

Fig. 1 HVOF gun for thermal spraying

TABLE I
HVOF Thermal Spraying Parameters and Levels

	Input	L1	L2	L3
A	Spray distance (mm)	170	200	250
B	O/F ratio	2.5	3.5	4.3
C	Powder feed rate (g/min)	38	58	-
D	Gun travel speed(m/s)	1	1.2	-

II. Materials and Methods

In this study, the WC-12Co powder (HC Starck Co.) with particle size of 15-45 µm was used. Widely used AISI1045 steel was considered for substrate. The substrate surface was sandblasted by alumina particles with 16 micron mesh. Spray Watch diagnostic system (Oseir, Finland) was used for monitoring the particles temperature. The levels of parameters are tabulated in Table I. The Taguchi approach was used for design of experiments based on the average of outputs. Applying the Taguchi method can be considered as a low-cost method to optimize the thermal spraying processes.

Philips X-ray diffractometer with Cu-Kα radiation and scanning electron microscopy (SEM) was used to determine the phase, morphology, the microstructure as well as thickness of the powders and coating.

III. Results and Discussion

A. Microstructure and XRD Studies

Fig. 2 illustrates the XRD pattern of WC-12Co powder. As it can be seen from the patterns the peaks are attributed to WC,

M.Jalali Azizpour is with Department of Mechanics, Collage of Engineering, Ahvaz branch, Islamic Azad University, Ahvaz, Iran (e-mail: mjalali@iauahvaz.ac.ir).
H. Mohammadi Majd is with PTRI of ACECR.

Co and free carbon. Fig. 3 illustrates the XRD pattern of the coating. As can be seen the patterns correspond to presence of WC, W_2C and W_3Co_3C. The presence of W_2C and W_3Co_3C are thought to be due to decomposition of WC at high temperature of flame and abundant amount of oxygen when the powders are accelerated. Oxidation of WC-Co occurs in two ways, either in a solid or molten state.

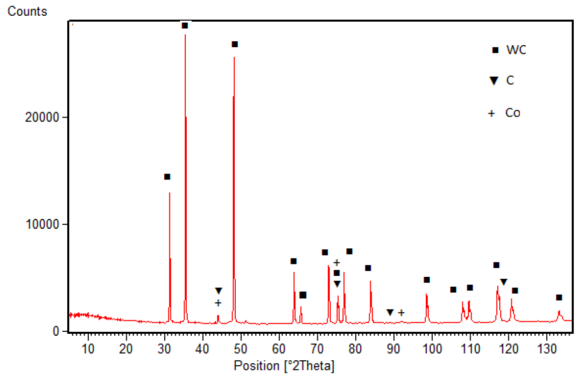

Fig. 2 XRD pattern of WC-12Co powder

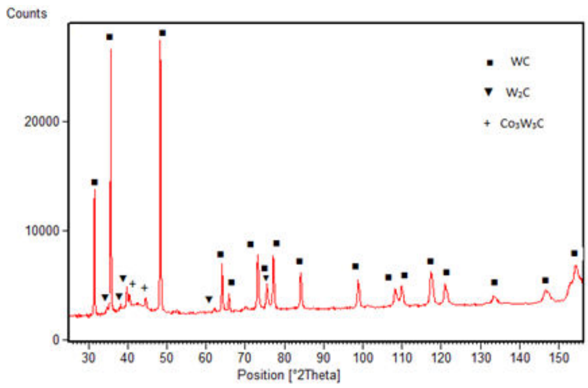

Fig. 3 XRD pattern of WC-12Co coating

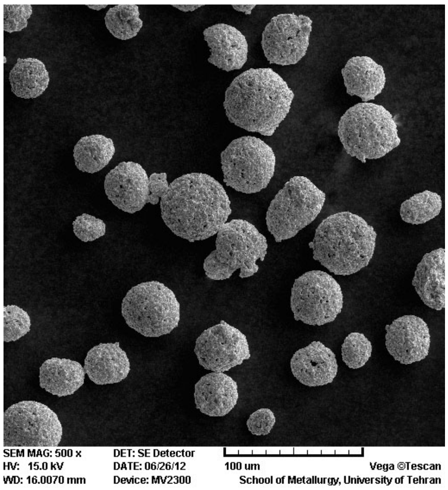

Fig. 4 Particle morphology in 500x magnification

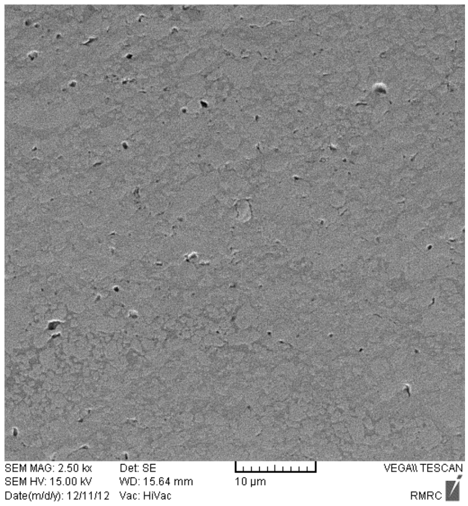

Fig. 5 SEM micrograph of WC-12Co coating

B. Morphological Characterization

Fig. 4 illustrates the Scanning Electron Microscopy (SEM) morphology of agglomerated- sintered WC-12Co powder in 500x. As observed the particles are spherical and uniformly distributed (15-45 µm) with high porosity. Fig. 5 illustrates a general view of the coating after metallographic preparation. The WC-12Co HVOF thermally sprayed coating appear to be quiet dense.

C. Design of Experiments

Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on "ORTHOGONAL ARRAY" experiments which gives much reduced "variance" for the experiment with "optimum settings "of control parameters. Thus the marriage of Design of Experiments with optimization of control parameters to obtain BEST results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

In this study the Taguchi fractional factorial method was used for finding the optimum conditions of coating thickness and evaluation the response of the optimum conditions.

1. The Effect of Spraying Factors on the Thickness

For factors and selected levels in this study, Taguchi approach suggests L9 standard array. Taguchi orthogonal array and the average of coating thickness in each condition are tabulated in Table II. The particles have different kinetic energy in impact due to particle size distribution in feedstock. Particle size distribution shows that 50% of the particles have diameter of 34.3µm.

Online diagnostics as shown in Fig. 5 using Spray watch 2i equipment were carried out at different spray conditions to measure the particle velocity and temperature. The impact temperature distribution of more than 3000 monitored particles in this study is illustrated in Fig. 6. The quality characterization was selected to be the bigger the better.

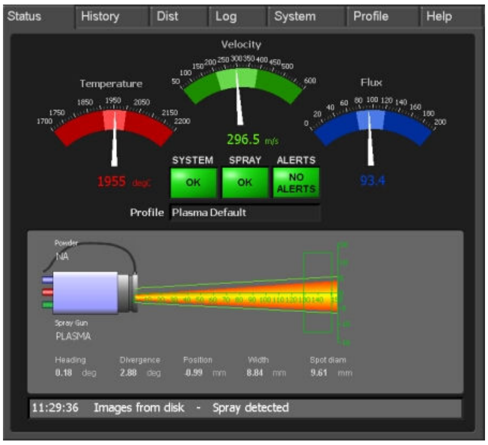

Fig. 6 Spray watch diagnostic system

For the bigger the better quality characterization the optimum thickness of 345.5 µm was obtained for the A3/B3/C2/D1 test condition. As the A3/B3/C2/D1 condition is existed in the used standard array, validation test was not conducted for this purpose. The response in A1/B2/C1/D1 test condition shows that the coating thickness is V=355µm which has good agreement with optimum result of Taguchi approach.

TABLE II
TAGUCHI ARRAY FOR THIS DOE

Test No.	A	B	C	D	Thickness, µm
E1	1	1	1	1	195
E2	1	2	2	2	236.25
E3	1	3	1	1	212.5
E4	2	1	2	1	288.75
E5	2	2	1	1	257.5
E6	2	3	1	2	298
E7	3	1	1	2	269.5
E8	3	2	1	1	289
E9	3	3	2	1	355

The average effect of spray parameter on the obtained coating thickness is shown in Figs. 7-9. The particle velocities were measured in previous study [10]. The particle velocity decreased by increasing the spray distance but it can be seen that the thickness increased by spray distance. This should be in result of decreasing in splash ratio. In case of oxygen to fuel ratio the increasing trend of particle velocity is not permanent and decreases in level3 (F/O=4.3). But the increasing trend is permanent.

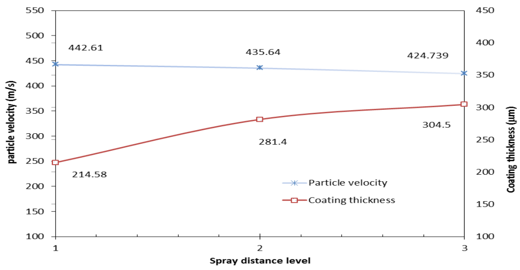

Fig. 7 Effect of SD on Temperature and thickness

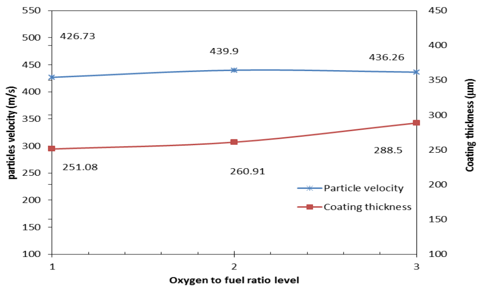

Fig. 8 Effect of O/F ratio on temperature and thickness

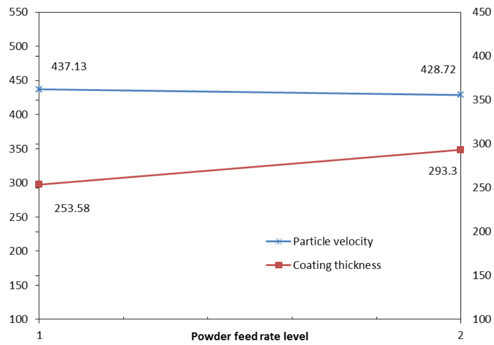

Fig. 9 Effect of feed rate on temperature and thickness

IV. CONCLUSION

In this study the effect of thermal spraying process parameters on particle characteristics and thickness of WC-12Co coating on AISI1045 substrate has been investigated. A summary of conclusions is as follow:

- The response in A1/B2/C1/D1 test condition shows that the coating thickness is V=355µm which has good agreement with optimum result of Taguchi approach.
- Spray distance has the strongest influence on the thickness with near to 70 percent participation.

REFERENCES

[1] M. HeydarzadehSohi, F.Ghadami, Comparative tribological study of air plasma sprayed WC–12%Co coating versus conventional hard chromium electrodeposit, Tribology International, 2009.

[2] Y.Y. Santana, Characterization and residual stresses of WC–Co thermally sprayed coatings, Surface & Coatings Technology 202 (2008) 4560–4565

[3] C. Lyphout, Residual Stresses Distribution through Thick HVOF Sprayed Inconel 718 Coatings, Journal of Thermal Spray Technology, Volume 17(5-6) Mid-December 2008—915.
[4] Stewart DA, Shipway PH, McCartney DG. Microstructural evolution in thermally sprayed WC–Co coatingsActa Mater 2000;48:1593–604.
[5] Yang Q, Senda T, Ohmori A. Effect of carbide grain size on microstructure and sliding wear behavior of HVOF-sprayed WC–12% Co coatings. Wear 2003;254:23–34.
[6] T.C. Totemeier, R.N. Wright, W.D. Swank, Metall. Mater. Trans., A Phys. Metall. Mater. Sci. 35 (6) (2004) 1807.
[7] T.C. Totemeier, R.N. Wright, Surf. Coat. Technol. 200 (12-13) (2006) 3955.
[8] J.C. Smithells, Metals Reference Book, 5th editionButterworths, London, 1976.
[9] T.C. Totemeier, Residual stress determination in thermally sprayed coatings—a comparison of curvature models and X-ray techniques, Surface & Coatings Technology 200 (2006) 3955 – 3962.
[10] M.Jalali Azizpour, S.Nourouzi, The effect of spray parameters on the WC-12Co particles velocity, Iranian Journal of surface science, vol16(45-53)2013.