 ISSN : 2249-5762 (Online) | ISSN : 2249-5770 (Print)

Evaluation of Erosion Wear of HVOF Sprayed Al-Si Polyester Abradable Coating by Taguchi Method

[1]Shekhar Sharsar, [2]Ram Bhagat, [3]Nitin Kapoor
[1,3]Dept. of Mechanical Engineering, Panipat Institute of Engg. and Tech., Panipat, Haryana, India

Abstract
This work presents successful implementation of Taguchi experimental design to develop a successful and efficient method of evaluation and predicting the erosion wear response of Aluminum-Silicon Polyester abradable coatings prepared by High Velocity Oxy-fuel spraying technique on a titanium substrate. HVOF technology utilizes the exotic properties of the fuel and oxygen, chemical reactions to produce combusted products and powder supplied along with the combusted products and imparts new functional properties to conventional materials. The erosion wear of Aluminum-Silicon Polyester abradable coating were investigated by a self made high temperature air jet erosion testing machine. The result shows that the relationship between erosion rate and impact velocity is an exponential function. Further, when Erosion wear behavior of the coating was investigated at three impact angles (i.e. at 30^0, 60^0, 75^0), revealed that maximum erosion takes place at 75^0 impact angle. Erosion resistance of abradable coating depends upon the hardness of the coating. Polyester plays a very important role here and increases the erosion resistance.

Keywords
High Velocity Oxy-fuel technique, Titanium, Al-Si Polyester coating, Taguchi methods.

I. Introduction

Surface modification is an important term which can be helpful for achieving increased reliability and enhanced performance of industrial components. The various critical components are therefore, subjected to more rapid degradation and the components parts fail to withstand the changing and heavy operating conditions and this has been taking a decreasing of industry's economy. In an large number of cases, the increased damage of parts and their eventual failure have been traced to material damage brought about by their environments and also by high relative motion between mating surfaces, cyclic stresses, corrosive media, extreme temperatures etc.

Thus, a protective coating is used between the surfaces of the component and the aggressive environment and it is act as a barrier between surface and environment. It is advantageous and accepted globally to be an attractive means to significantly reduce damage to the actual component by acting as the first line of defense.

For example in turbo machinery the clearance between blades tips and the casing must account for changes in concentricity as well as thermal expansion due to shock loading events. To prevent blade tip to casing contact, large clearances must be employed. But with the help of thermal spray abradable coating minimum clearance between blade tip and casing is maintained. Similarly in aircraft jet engines abradable coatings are used in the compressor and turbine sections where a minimum clearance is required between the blade tips and the casing [1].

Due to operational requirements in dusty environments, study of erosion characteristics of these Al-Si-Polyester coatings is of high relevance [2]. Solid particle erosion is a dynamic process that leads to progressive loss of material from the target surface due to impingement of fast moving solid particles. The solid particle erosion or loss of material of abradable coating results from repeated impact of small, solid particles entrained in air or gas [3]. During flight, a particle carries momentum and kinetic energy, which is dissipated during impact at target surface. The mass loss due to erosion increases with the increase in kinetic energy of the particles impact at the target surface [4]. The erosion wear due to the air particles in some devices such as jet planes and turbines is also significant due to very high impacting velocity. So, the analysis of erosion wear of abradable coating is of great importance and requires deep research in this field. Statistical techniques are very useful for analysis and reduce the overall calculation and save time.

II. Experimental

A. Preparation of Substrate (Titanium)

Titanium is a metallic element known for his high strength-to-weight ratio. Titanium is 60% more dense than aluminum, but more than twice as strong as the most commonly used materials. However, titanium loses strength when heated above 430°C (806°F).

B. Coating Material (Al-Si Polyester)

Al-Si polyester powder was especially developed for machine element clearance control. Al-Si Polyester Coating have a high degree of abradability with essentially no blade tip wear, excellent resistance to oxidation at temperatures up to (345°C) 650°F and good resistance to thermal shock. The aluminum provides good bond strength, good interparticle strength and good thermal properties. The polyester provides abradability and a low coefficient of friction. Erosion resistance of abradable coating depends upon the hardness of the coating.

C. Coating Procedure

In High velocity oxy-fuel coating process as shown in fig. 1 the fuel (Gas/Liquid) along with oxygen is supplied into the combustion chamber where it burnt and high temperature pressure combustion products exhausted through nozzle. The powder to be coated is supplied along with this superheated high velocity stream. In this process, a very high temperature of 3000^{0}C achieved through fuel gas combustion. A very high velocity of about 800 m/s was used during the process.

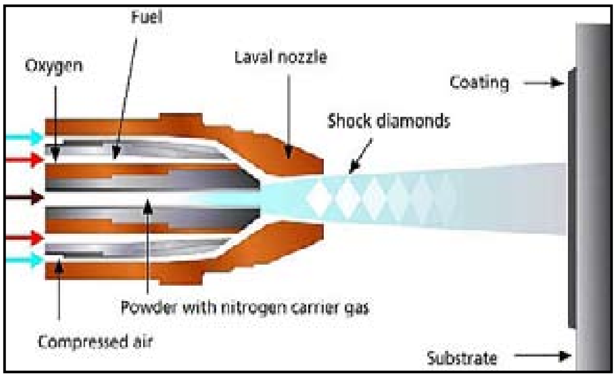

Fig. 1: High Velocity Oxy-Fuel [1]

Coating Composition- Si 12% + Al 60% + Polyester 40%
Coating Thickness- 2 mm
Melting Point- (approximate) softens at 425° C
Hardness- 51
Porosity- 29.91%

D. Experimental Setup

The high temperature air jet erosion testing machine fig. 2 is usually based upon the 'sand blast' method, where solid particles are carried in an air flow and impacted onto a stationary target. The self-made High temperature air jet erosion testing machine has capability of either heating of air or heating of specimen or both air as well as specimen is heating.

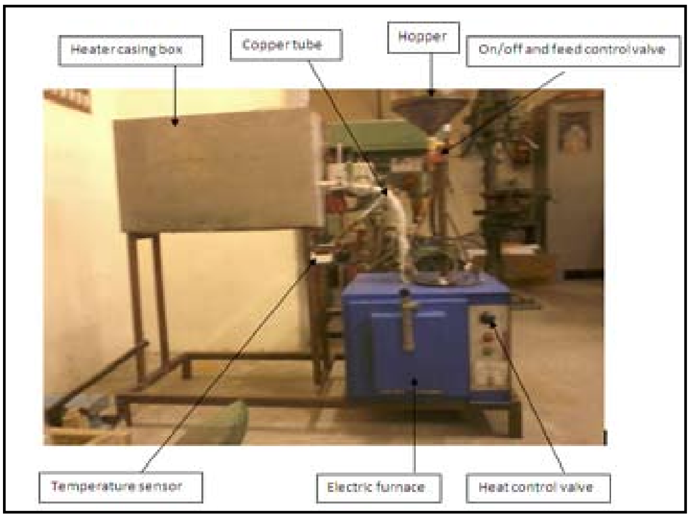

Fig. 2: High Temperature Air Jet Erosion Testing Machine

The self-made High temperature air jet erosion testing machine has capability of either heating of air or heating of specimen or both air as well as specimen is heating. The experiment was done by heating the specimen in the range of 100^{0}C to 400^{o}C temperature with the help of electric furnace. A high velocity air jet strikes a flat specimen at some adjustable angle. In this test, the specimen is taken inside the electric furnace at different angle usually 30^0, 60^0 and 75^0 with the help of specimen holder.

E. Design of Experiments

Taguchi technique creates a standard orthogonal array to accommodate the effect of several factors on the target value and defines the plan of experiments [5]. The Experiments were conducted as per the standard orthogonal array so as to investigate which design parameter significantly affects the erosion wear for the selected combinations of impact speed and impact angle etc.

In Table 1 represents control factor and their selected levels. Each row represents a test parameter whereas a column represents levels of experiments or parameter levels. The experimental observations are further transformed into signal-to-noise (S/N) ratio. The S/N ratio for minimum erosion rate can be expressed as ''smaller is better'' characteristic, which is calculated as [6]

$$\left(\frac{S}{N}\right)_{LB} = -10\ \log(MSD_{LB})$$

Where $MSD_{LB} = \frac{1}{R}\sum_{j=1}^{R}(y_j^2)$, R the number of observations, and y_j the observed data.

Table 1: Control Factors and Levels

Control factors	Levels			Units
	1	2	3	
Impact velocity A	30	50	70	m/sec
Impingement angle B	30	60	75	degree
Erodent size C	50	100	150	micron
Substrate temp. D	100	300	400	Degree C

F. Experimental Procedure

A high temperature erosion testing machine was used to perform erosion test on metal substrates with Al-Si Polyester coating is carried out at different impingement angles ranging from 5-75 degree. Dry sand particles of different average sizes are used as erodent. The machine is as per ASTM G76 standards. A simple working principle of erosion testing machine is shown in fig.3. In air jet erosion testing a high velocity jet strikes a flat specimen at some adjustable angle. In this test, the amount of material removed is determined by the weight loss. The weight loss of the specimen corresponds to the average erosion over the surface.

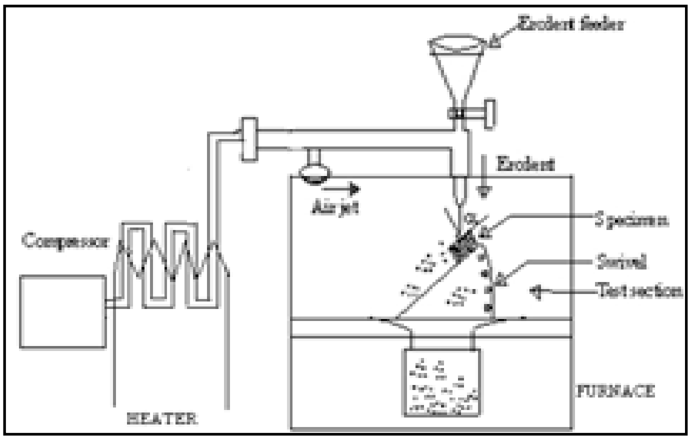

Fig. 3: Working Principle of Erosion Testing Machine

III. Result and Discussion

The Taguchi approach to experimentation provides an orderly way to collect, analyze, and interpret data to satisfy the objectives of the study. The experiments were conducted as per the standard orthogonal array so as to investigate which design parameter significantly affects the erosion wear for the selected combinations of impact velocity, impingement angle, erodent size and substrate temperature. Table2 shows the L9 Orthogonal Array and Erosion Test Results along with S/N Ratios. The analysis is made using the popular software MINITAB 15 which is specifically used for design of experiments. The graph plots fig. 4 shows the effect of each control factor impact velocity, impingement angle, erodent size and substrate temperature on erosion rate. From the fig.4 it is found that the

Table 2: L9 Orthogonal Array

Test Run	Impact Velocity A (m/sec)	Impinge-ment Angle B (degree)	Erodent Size C (micron)	Sub-strate Temp. D (deg)	Erosion Rate Er/10-3 (Mg/g)	S/N Ratio (db)
1	30	30	50	100	0.057	4.882
2	30	60	100	300	0.850	1.416
3	30	75	150	400	1.899	-5.570

 ISSN : 2249-5762 (Online) | ISSN : 2249-5770 (Print)

4	50	30	100	400	1.705	-4.634
5	50	60	150	100	1.636	-4.275
6	50	75	50	300	0.778	-2.180
7	70	30	150	300	2.280	-7.158
8	70	60	50	400	2.290	-7.196

relationship between erosion rate and impact velocity is exponential function and erosion rate increase with increase of impact velocity.

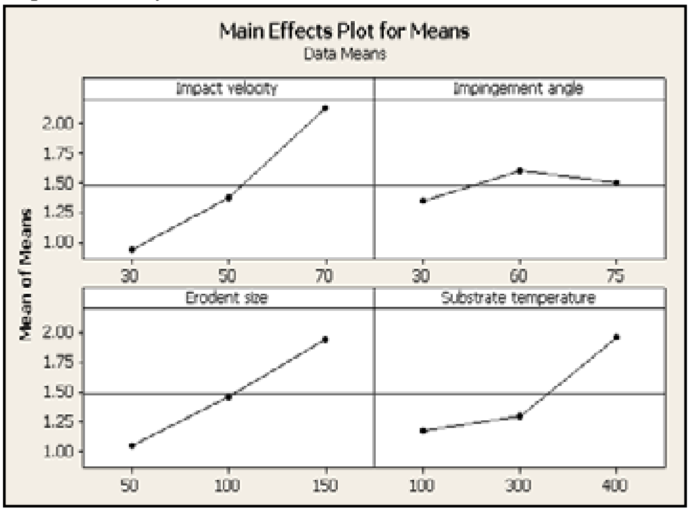

Fig. 4: Effect of Control Factor of Means

Similarly, In case of erodent size and substrate temperature, the erosion rate increase with increase of erodent size and substrate temperature. The impact angle shows maximum erosion rate at 60^0 and after that with increase of impact angle erosion rate starts decreasing.
It is evident from the response Table 3 that the factor combination A_2, B_3, C_2 and D_2 will give the minimum erosion rate and the most significant factor which effect maximum to erosion wear is impact velocity.

Table 3: Response Table for Signal to Noise Ratios for smaller is Better

Levels	Impact velocity A	Impingement angle B	Erodent size C	Substrate temp D
1	6.908	4.363	6.622	5.151
2	-2.243	-3.354	-2.792	-1.189
3	-6.503	-2.848	-5.668	-5.801
delta	13.411	7.717	12.290	10.952
Rank	1	4	2	3

IV. Conclusion

1. At 60^o impact angle Al-Si Polyester coating has maximum erosion rate. With increase of impact angle above 60o the erosion rate starts decreasing. This is due to abrasive particle strikes and extrudes the surface of coating and results in indentation and extruded lips formation and then lips become work-hardened by repeated impact of particles. So, the erosion wear of coating decreases after 60^0 impact angle.
2. The impact velocity has dominant effect on materials removal rate and with increase of impact velocity Al-Si Polyester coating erosion rate increase. The relationship between erosion rate and impact velocity is exponential function.
3. Erosion resistance of abradable coating depends upon the hardness of the coating. Polyester plays a very important role here and increases the erosion resistance.
4. Erodent size affects the erosion rate. With increase of erodent size the coating will have maximum erosion rate.
5. Substrate temperature is also one of the prominent parameter, which affect erosion wear. The erosion wear increases with increase in substrate temperature.
6. Solid particle erosion characteristics of Al-Si Polyester coatings have been successfully analyzed using Taguchi experimental design. Impact velocity, erodent size and substrate temperature in declining sequence are found to be significant for minimizing the erosion rate of coatings. Impingement angle is identified as the least influencing control factor for erosion rate.

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Shekhar Sharsar received his B.Tech degree in Mechanical Engineering from Panipat Institute of Engineering and Technology, Panipat, Kurukshetra University, in 2011, the M.Tech degree in Industrial and Production Engineering from University Institute of Engineering and Technology, Kurukshetra University, Kurukshetra in 2013. He is Assistant Professor, with Department of Mechanical Engg. in Panipat Institute of Engineering & Technology, Samalkha, Panipat (Haryana). He has one years teaching experience in Mechanical engineering.

Ram Bhagat received his B.Tech degree in Mechanical Engineering from J.I.E.T Jind, Kurukshetra University, in 2009, the M Tech degree in Industrial and Production Engineering from University Institute of Engineering and Technology, Kurukshetra University, Kurukshetra in 2013.

Nitin Kapoor received his B. Tech. Degree in Mechanical Engineering from Jind Institute of Engineering and Technology, Jind under Kurukshetra University, in 2005, C-DAC from Pune University in 2008, Pune (Maharashtra), M.B.A in HR from Guru Jambeshwar University in 2008 and M. Tech. Degree in Mechanical Engg. From Guru Jambeshwar University of Science and Technology, Hisar, (Haryana) in 2013. Nitin Kapoor worked in industry for 5 years in Production in THAI Sumit Pvt. Ltd & AirLink Engineers, Bristlecone, Mahindra base company as SAP Administrator and is working as an Assistant Professor, with Department of Mechanical Engg. in Panipat Institute of Engineering and Technology, Samalkha Near Panipat (Haryana).