Experimental analysis of processing parameter of thermal spray coating machine

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Abstract - **Thermal spray coating process are surface modification treatment process in which molted and semi-molted material spray on workpiece material with high temperature and high velocity. Thermal spray techniques are classified in different types of techniques: Detonation Gun spray, flame spray with wire, flame spray with powder, HVOF, plasma spray, wire arc spray, cold spray process. In this research paper briefly defined basic principle, advantages, limitations, process and focused on plasma process. The present research work focused on the study of nickel-aluminide deposition as the top coat on metallic workpiece without any intermediate bond coat. Mild steel are taken as the workpiece material and the deposition of Ni-Al is made by atmospheric plasma spray coating process. The basic aim has been to study the Found less porosity and high thickness of Mild steel workpiece material deposition of Ni-Al coatings. After experiment in this research work for analysis using minitab software and got best range of coating regarding to porosity, thickness.**

keywords - **Thermal Spray Techniques, Plasma Spray, Porosity, Thickness, DOE, Taguchi**

I. INTRODUCTION

All manuscripts must be in English. Coating can be defined as a layer of molted or semi-molted material formed naturally or artificially deposition on the surface of workpiece material. This coating is provided one physical barrier between our workpiece and atmosphere. Somany various reasons are available for coating on new parts on machine like protect new parts of machine against wear, corrosion, erosion, high temperature, moisture etc. Coating acts as a protective her in the different infrastructure like pipelines, mining equipment, tunnels where durability is the major importance as well as in many industries like automotive, aerospace, oil and gas mining, shipbuilding etc. In some cases the coatings are used to improve the surface properties like adhesive corrosion resistance, wear resistance.Surface modification is a generic term now applied to a large field of diverse technologies that can be gainfully harnessed to achieve increased reliability and enhanced performance of industrial components.The overall utility of the surface engineering approach is further augmented by the fact that modifications to the component surface can be metallurgical, mechanical, chemical or physical. Surface modification technologies have grown rapidly, both in terms of finding better solutions and in the number of technology variants available, to offer a wide range of quality and cost.Surface treatment process can are removing material, adding material and chemically altering the surface of different types of materials. Surface treatments are widely used in most industries to provide improved surface properties of a machine component.
Different types of surface treatments or process are available in industry

- Anodizing
- Galvanizing
- Lubricants
- Thermal spray coating
- Polymer film etc

Thermal spraying technology

From all of the above techniques, thermal spraying is popular for its wide range of applicability, adhesion of coating with the substrate and durability. Thermal spraying techniques are surface modification process in which melted (or heated) materials are sprayed onto a substrate surface. The feedstock (coating precursor) is heated by electrical (plasma or arc) or chemical means (combustion flame). Thermal spraying technology are divided into other two types

- Gas combination processess
- Arc processess

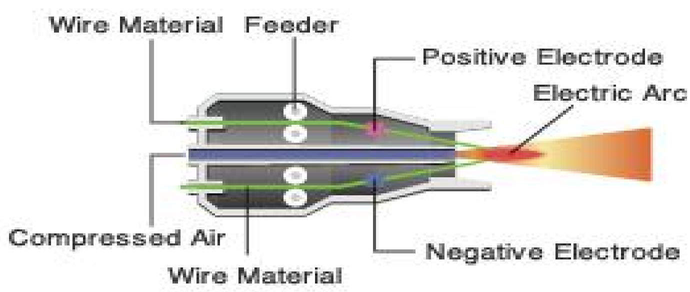
Various advantages of thermal spray technique

- Wide range of coating material(metals, alloys, ceramic, carbide)
- Rebuilt part very quickly & low cost

Further classification of thermal spray process

Electric Wire Arc Spray

In the electric arc spray process, two consumable wire eletrodes connected to a high-current direct-current (dc) power source are fed into the gun and establishing an arc between them that melts the tips of the wires. The process is energy efficient because all of the input energy is used to melt the metal. The process is capable of spraying at a very high deposition rate.



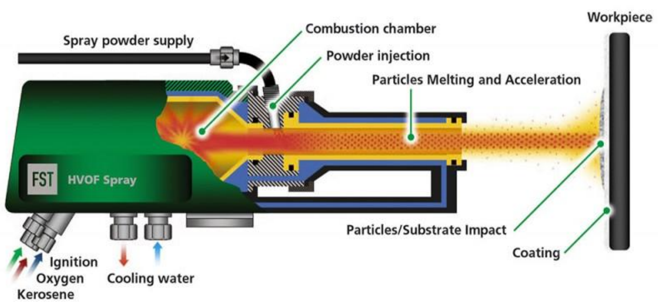


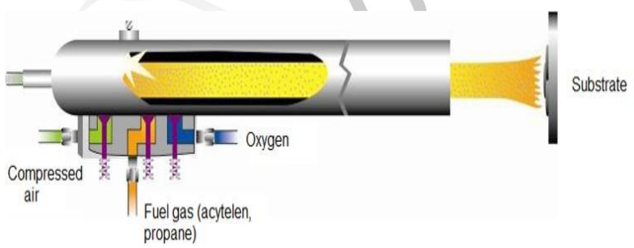
Fig. 1 Electric wire arc spray[21]   Fig. 2 HVOF[22]

High Velocity Oxy-Fuel(HVOF)

In the HVOF process fuel and oxygen are introduced to the combustion chamber together with the spray powder. The combustion of the gases produces a high temperaure and high pressure in the chamber. which causes supersonic flow of gas through the nozzle. Advantages of this spraying technique include good substrate-coating adhesion, high coating density. It is applicable to both metals and ceramics. It involves lessset up cost as compared to plasma or detonation gun.

Detonation gun process

The basic set up is shown in Figure. powder material is fed into the detonation gun with very small gas pressure. The valves are opened & allow oxygen and acetylene to enter into the combustion chamber of the gun. The gas and material mixture are then detonated by the sparks from spark plugs and an explosion occurs in gun. But the process is expensive and involves very elaborate arrangement. The process also produced very high noise.



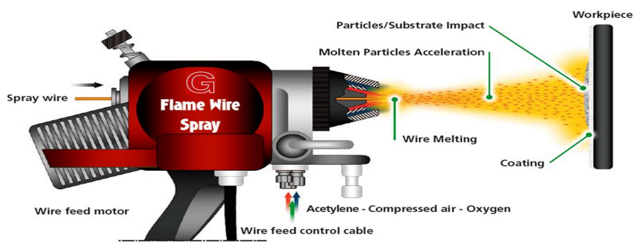


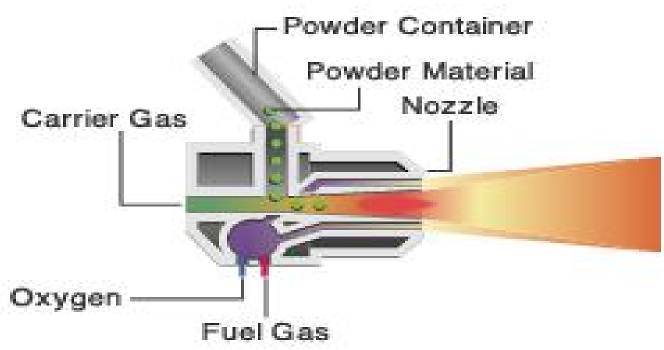
Fig. 3 Detonation gun[19] Fig. 4 Flame spraying with wire[23]

Flame spraying with wire

This type of arrangement is shown in figure, and the set-up consists of a spraying gun, a wire feed stock, drive roller, oxygen and acetylene gas cylinders, nozzle and an air compressor. A mixture of oxygen and acetylene is enter inside spraying gun and mixture contact with wire form material and convert in molted or semi-molted. Flame spraying is oldest of the thermal spraying processes characterized by low capialinvestment, high deposition rates and efficiencies. and relative ease of operation and cost of equipment maintenance.

Flame spraying with powder

This type of arrangement is shown in Figure 1.3. The flame spraying with powder process is carried out with one gun in which provide facility for fuel & gas (oxy-acetylene) injection and powder storage are joined with gun upper side.The powder form material are kept inside the hopper combined with the gun and can be released to the flame by the action of a trigger. After this process material contact with flame deposition on workpiece with high temperature and high pressure.



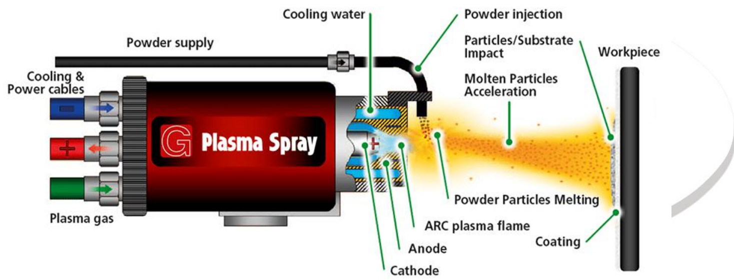


Fig. 5 Flame spraying with powder.[24] Fig. 6 Plasma spray process[20]

Plasma spraying process

Plasma arc spraying is one of the most sophisticated and Nersatile thermal spray methods. As the plasma spray process uses a DC electric arc to generate a stream of high temperatire ionized plasma gas. which acts as the spraying heat source. The plasma gun comprises a copper anode and tungsten cathode, both of which are water cooled. A high frequency arc is ignited between them.

Advantages of plasma spray technique

- Almost all types of materials are used in plasma process
- Plasma spray process is more suitable for high melting point materials like ceramic, alloys, refactory etc
- Compare to others process plasma given more homogeneous coating
- Plasma spraying process is more environmentally friendly process compare to others traditional coating

Disadvantages of plasma spray technique

- Less workers used in this process so unemployment issue raised against this process
- High initial setup cost in this process so not suitable in small scale production

Applications of thermal spray technique

- Steel industry
- Aircraft industry
- Automotive industry
- Medical industry
- Foundary & rolling mills

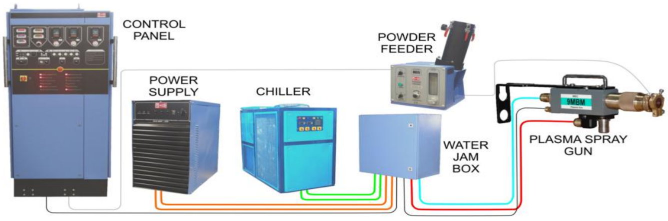
II. EXPERIMENTATION

Wherever In this present work,I used Commercially available mild steel (Ms) were chosen as the workpiece materials for the present work. The specimens are rectangular in shape having a dimension 50 mm x 50 mm x 2 mm. The specimens were grit blasted at a pressure of 3 kg/cm2 using grits having a grit size of 60. The standoff distance in shot blasting was kept between 120-150 mm. The average roughness of the substrates is 6.8 µm. The grit blasted specimens were cleaned with acetone. Spraying is carried out immediately after cleaning. Nickel and aluminium metal powders of commercial grades are used to produce nickel aluminide coating.These two powders Ni : Al were thoroughly mixed in ratio 3:1 by weight. The particle size range the powders used in this study, are giving below table

Table 1. Partial Size

Powder	Range
Aluminium	-106µm to +53µm
Nickel	-74 Aµm to +53 µm

The spraying we will use APS (atmospheric plasma spray) system at silicon metallizing service limited, bakrol Ahmedabad.Argon is used as the primary plasma gas and nitrogen as the secondary gas. The powders are deposited at spraying angle of 90°. The powder feeding is external to the gun. General arrangement of of the plasma Spraying equipment.



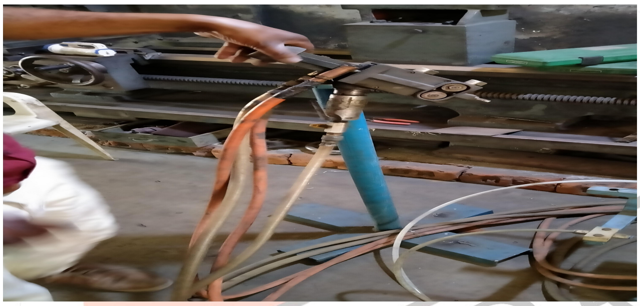


Fig. 7 General arrangement of plasma equipment. Fig. 8 Plasma gun

III. METHODOLOGY

Design of Experiment(DOE)

A scientific approach to plan the experiments is a necessity for efficient conduct of experiments. When the problem involves data that are subjected to experimental error, statistical methodology is the only objective approach to analysis. Thus, there are two aspects of an experimental problem: the design of the experiments and the statistical analysis of the data.The advantages of design of experiments are as follows:

- Numbers of trials is significantly reduced.
- Optimal setting of the parameters can be found out.
- Experimental error can be estimated.

DOE is a technique of defining and finding all possible combinations in an experiment involving multiple factors and to identity the best combination set. In this, different levels and their factors are identified.It is important note that not all variables affect the performance in the same manner. Some may have no influences on the output performance, some may have medium influence and some have highly influence at all.Thus Design of experiment (DOE) is a method to identify the important factors in a process, identify and fix the problem in a process, and also identify the nearest possibility of estimating interactions. The various methods of Design of Experiment are as follows:

- Full factorial method
- Taguchi method
- Mixture method
- Response surface method

L9 Orthogonal Array

In the present work, the L9 orthogonal Array methodology has been used to plan the experiments. Taguchi developed some statistical methods to improve the qualities of manufactures goods known as Taguchi methods.The design of experiments is used to find the best combination of input variables in an orthogonal array. In this experiment the input parameters considered are Input power, stand-off distance, and material flow rate. Since three factors are chosen the design becomes a 3 level 3 factorial Taguchi design. L9 orthogonal array was chosen for the experiments to be conducted. The version 16 of the MINITAB software was used to develop the experimental plan for L9 Orthogonal Array.

Table 2. factors & levels

Symbol	Input parameters	Level 1	Level 2	Level 3
A	Input power(KW)	15	20	25
B	Material flow rate(g/min)	50	100	150
C	Stand off distance(mm)	100	150	200

IV. RESULTS AND DISCUSSION

Taguchi's L9 experimental plan is followed for the investigation and results obtained are tabulated for the various combinations of process parameters as shown in Table 3. The study shows that higher thickness was recorded in the experiment run number 3 (i.e. input Power- 15kw , powder feed rate - 150 g/min, stand-off distance - 200 mm). Less porosity was noticed in the run 6 (i.e. input power -20 KW, powder feed rate - 150 g/min, stand-off distance - 200 mm)

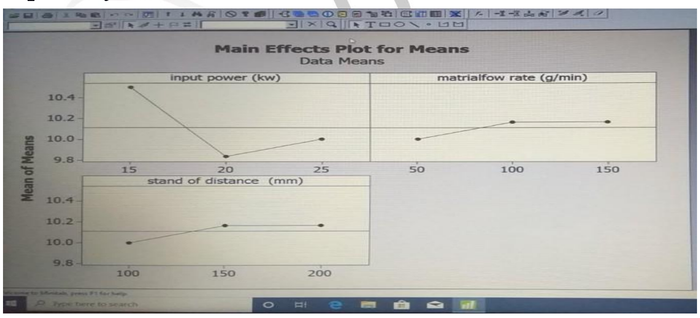
Table 3. Experiment result table

Sr.Number	Input power(KW)	Material flow rate(g/min)	Stand-off distance(mm)	Porosity(%)	Thickness (micron)
1	15	50	100	10	80
2	15	100	150	10.5	120
3	15	150	200	11	150
4	20	50	100	10	50
5	20	100	150	10.5	70
6	20	150	200	9	90
7	25	50	100	10	90
8	25	100	150	9.5	60
9	25	150	200	10	80

Analysis of Variance (ANOVA)

The Analysis of Variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiment to determine the present contribution of each factors. Study of ANOVA table for a given analysis helps to determine which of the factors need control and which do not. Analysis provides the variance of controllable and noise factors. Analysis of the experimental data obtained from taguchi design runs is done on MINITAB 16 software linear response surface model.

Effect of process parameters on porosity



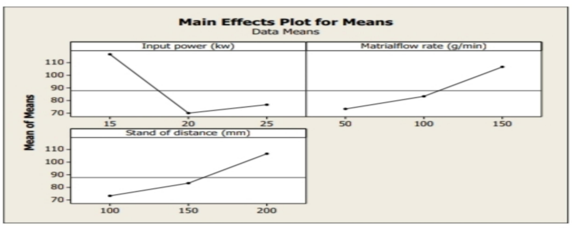


Fig 9 main effect plot for porosity. Fig 10 main effect plot for thickness

From the figure 9, it can be seen that :-
Effect of Input Power: Porosity is a slight decrease with the increase in Input Power then slight increase with increase Porosity.
Effect of Abrasive Flow Rate: Porosity is an increase with the increase in material Flow Rate.
Effect of Stand off Distance: Porosity is a slight increase then slight continue with the increase in Stand off Distance.

Effect of process parameters on thickness

From the figure 10, it can be seen that :-
Effect of Input Power : Thickness is decrease with the increase in Input Power & very slightly increase with increase input power.
Effect of Material Flow Rate: Thickness is an increase with an increase material Flow Rate.
Effect of Stand off Distance: Thickness is an increase with the increase in Stand off Distance.

S/N ratio graph for porosity

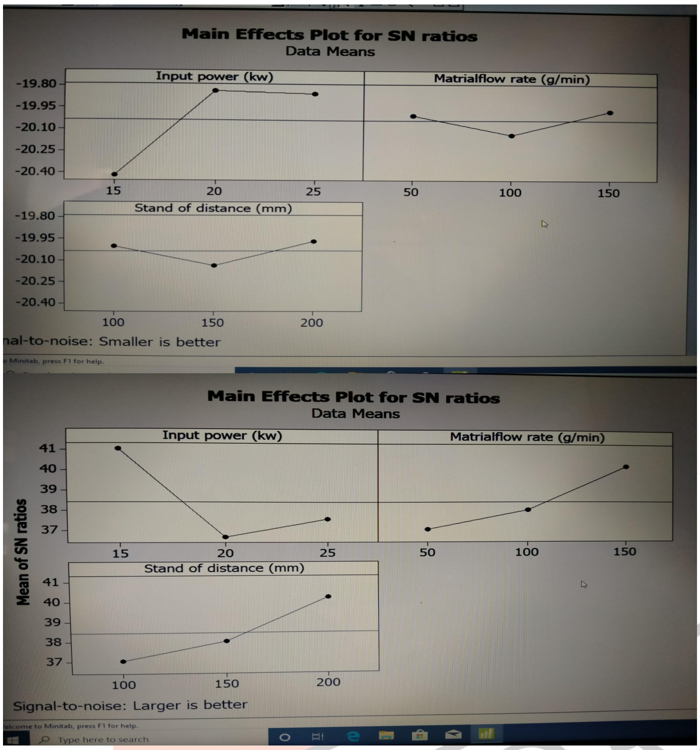


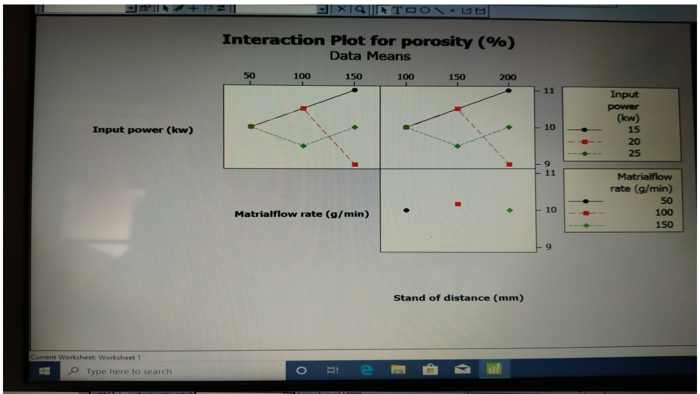
Fig. 11 S/N ratio graph for porosity. Fig. 12 S/N ratio graph for thickness

This graph is show in fig 11, that smaller is better value, so I can say that three best value for porosity is 20kw input power and 150 g/min material flow rate and 200mm stand off distance.

S/N ratio graph for thickness

The graph is show in fig 12, that larger is better, so we can say three best value for thickness is 15kw input power, 150 g/min material flow rate, 200mm stand off distance.

Interaction Plot for porosity



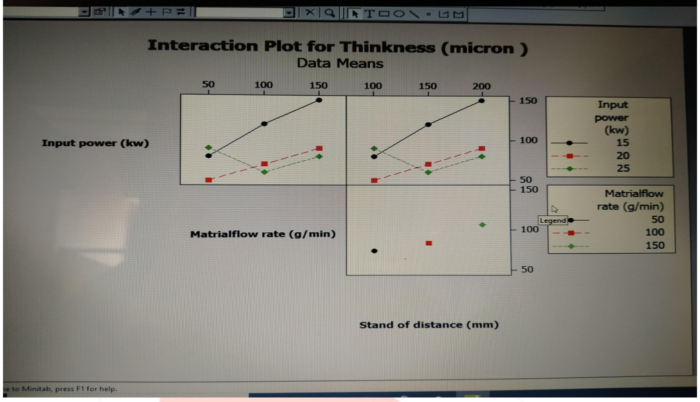


Fig 13 Interaction plot for porosity. Fig. 14 interaction plot for thickness

The interaction plot in Figure 13, suggests interactions. As the lines are not parallel; meaning the change in any one parameter will have effect on other parameters.

Interaction Plot for Thickness

The interaction plot in Figure 14, suggests interactions. As the lines are not parallel; meaning the change in any one parameter will have effect on other parameters.

Regression Model Analysis for Porosity

The Regression equation is

porosity (%) = 11.4 - 0.0667 Input power (kw) + 0.00001 Matrial flow rate (g/min) (1)

Regression Model Analysis for Thickness

The Regression equation is

Thinkness (micron) = 134 - 4.00 Input power (kw) + 0.333 Matrial flow rate (g/min). (2)

Validation Through Practical Experiment

The results obtained through analysis in minitab software 16 had to be validated. This was done through practical performance of the experiment in the same manner as the practicals performed earlier as per DOE.

Table 4. Valedictory experiment for porosity

Input parameters	Best analysis value for porosity(%)	Best experimental value for porosity(%)	Error(%)
Input power(KW)	20	20	0.0%
Material flow rate(g/min)	150	150	0.0%
Stand off distance(mm)	200	200	0.0%

Table 5. Valedictory experiment for thickness

Input parameters	Best analysis value for thickness(micron)	Best experimental value of thickness(micron)	Error(%)
Input power(KW)	15	15	0.0%
Material flow rate(g/min)	150	150	0.0%
Stand off distance(mm)	200	200	0.0%

V. Conclusion

Now for the different set of three input variables main effect plot is done as per shown in above figure. And probability graph is also done as per the set of three input parameters. Interaction plot is also done using minitab software as per three different input parameters. Now I reached this following conclusions are made.

- By increasing material flow rate and stand-off distance, porosity(%) is increased which is shown in main effect plot.Also it can be seen that when increase input power, first porosity (%) decrease and slightly increase.
- By increasing material flow rate & stand of distance parameter thickness (micron) is increased & also it can be seen that thickness decrease with increase of input power and very small value increase with increase input power.
- Minitab software was able to reach the optimal solution, after satisfying the constraints. This was validated in present work practically, after performing a confirmatory experiment as per process parameters analysis by minitab software. Maximum error of 0.0% & 0.0% was found between the analysis value & the experimental value of output parameters of TSCM.

References

[1] Rakesh Kumar & Santosh Kumar "Thermal Spray Coating; A Study" International Journal Of Engineering Sciences & Research Technology ISSN: 2277-9655(Kumar "et at.. 7(3) March, 2018).

[2] Bhanu Pratap, Vijay Bhatt, Vikas Chaudhary "A Review on Thermal Spray Coating" International Journal of Scientific & Engineering Research, Volume 6, Issue 5, May-2015 ISSN-5518

[3] Sagar Amin, Hemant Panchal "A Review on Thermal Spray Coating Processes" International Journal of Current Trends in Engineering & Research e-ISSN 2455-1392 Volume 2 Issue 4, April 2016 pp.556-563

[4] Lachake Harshad Sanjay, Prof. Bhamre V.G., Prof. Londhe "A Review on Plasma Spray Coating And its characterization" International Research Journal of Engineering and Technology e-ISSN: 2395-0056 Volume:04 Issue: 07/July- 2017

[5] Armelle m vardelle " thermal spray coating "

[6] Thermal spray technology white paper" prepared by the thermal spray society affiliate of ASM International

[7] Dr S.Madhu, Arvind T.D, Vineel Satyakanth "A Research Review On Thermal Coating" International Journal of Engineering Research, ISSN 0973-4562 Vol.10 No.33 (2015) © Research India Publication

[8] Gustavo Bavaresco Sucharski, Anderson Geraldo marenda pukasiewicz "Optimization of the Deposition Parameter of HVOF FeMnCrSi+Ni+B Thermally Sprayed Coatings" soldagem & inspeco. 2015;20(2):238-252 Technical Papers

[9] Naveena B.E., R.Keshavamurthy and B.H.Channabasappa "Studies on parametric Optimization for Plasma Spray fly ash-Al2o3 composite Coating" Applied Mechanics and materials vols. 813-814 (2015) 511-515 © (2015) Trans tech publication, Switzerland

[10] Amir hossein pakserest, amir hossein javadi, Reza teimouri "Statistical analysis and multiobjective optimization of process parameters in plasma Spraying of partially stabilized zirconia" International advance manufacturing technology (2014) 75:735-753 DOI 10.1007/s00170-014-6169-9

[11] Somak Datta, Dilip Kumar pratihar & Parth Pratim bandyopadhyay "Modeling of plasma spray coating process using regression analysis" The International Journal of Advanced manufacturing technology, ISSN 0268-3768, Volume 65 combined 5-8

[12] Manjunath Patel G.C., Pradeep N.B., Girish L.,Harsh h.m. "Experimental analysis and optimization of plasma parameters on microhardness and wear loss of Mo-Ni-Cr coating super duplex stainless steel" Australian Journal of Mechanical engineering, DOI: 10.1080/14484846.2020.1808760(Taylor & Francis)

[13] H.L.de Villiers Lovelock, P.W.richter and P.M.young "Parameter study of HP/HVOF Deposited WC-CO coatings" Journal of thermal spray technology volume 7(1) march 1998-97

[14] Tarun Goyal, ravinderjit Singh Walla & t.s.sidhu "study of coating thickness of cold process using Taguchi method" material and manufacturing processes process, 27:185-192, 2012 copyright © Taylor and Francis group, LLC ISSN:1042-6914 print/1532-2475 online

[15] P.saravanan, v selvarajan, s.v.joshi "Experimental design and performance analysis of aluminium coating deposited by a detonation spray process" Journal of Physics D: Applied Physics. 34(2001) 131-140

[16] Serkan Ozel, Erdinc viral "Taguchi method for investigation of the effect of TBC coating on NiCr bond-coated diesel engine on exhaust gas emissions" International advance research and engineering journal volume 04 issue 01 April,2020

[17] M.Magnai, P.H. Suegama, N. Espallargas, s.dosta "Influence of HVOF parameters on the corrosion and wear resistance of WC-Co coating sprayed on AA7050 T7" surface & coating technology 202(2008) 4746-4757

[18] Z.Bergant and J.Grum "Quality Improvement of Flame Sprayed, Heat Treated, and Remelted NiCrBSi coating" Journal of thermal spray technology DOI: 10.1007/s11666-009-9304-7 1059-9630/$19.00 ©ASM Internationa

[19] https://www.plakart.pro/en/technologies/detonation-spraying-d-gun/

[20] https://www.griekspoorthermalcoatings.com/plasma-spraying

[21] https://www.tocalo.co.jp/english/technical/arc.html

[22] https://www.fst.nl/thermal-spray-equipment/modular-thermal-spray-systems/hvof-spray-systems/hvof-high-velocity-oxygen-fuel.html
[23] https://www.tocalo.co.jp/english/technical/powderflame.html
[24] https://www.griekspoorthermalcoatings.com/plasma-sprayingl