Gas Tunnel Type Plasma System for Clay Coating

Article history
Received
1 June 2018
Received in revised form
11 June 2018
Accepted
19 November 2018
Published
28 November 2018

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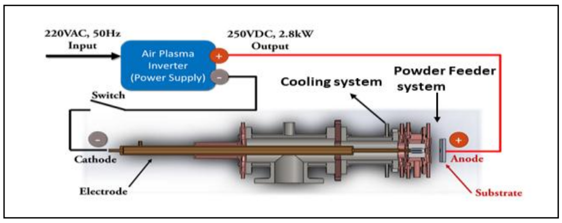
Graphical Abstract



Abstract

Modification on powder feeder concept enables better performance for gas tunnel plasma spraying. A powder delivery system with axial sandblast spray concept was modified and fabricated using 3D modelling. The present work was undertaken to investigate the difference in structure and thickness of clay coating manufactured by new system with manipulated flowrate and platting distance. Coating process using clay powder feed stock and stainless steel (316H) substrate was performed for different flowrate (4L/min and 5L/min) and at platting distance from 2mm to 10mm. Surface morphology of the coatings were characterized by Scanning Electron Microscope (SEM) and phase analyses was done by X – Ray Diffractometer (XRD). Optimum parameter was obtained at 5 L/min and distance of 10mm which producing an average coating thickness of 493 µm, good adhesion, smooth surface and changes of phases from illite and albite into Quartz. The results have indicated the sustainability of the plasma technique with regards to the production of a good quality ofceramic coated and having good adherence to the metal substrate.

Keywords

Ceramic Coating; Gas Tunnel Plasma Spray; Powder Feeder System; Clay Powder

Introduction

The development of coating technique had been commercializing throughout the world and their equipment was genuinely being introduced. However, there are 4 different type of techniques that widely been used which were; high – velocity oxy – fuel spraying (HVOF), wire arc spraying, plasma spraying (D.C current blown arc spraying) and powder flame spraying [1-5]. Each of the technique gives a different result of characteristic in terms of microstructural behaviour and surface morphology of the coated area. The techniques promising to give a desirable microstructural behaviour and surface morphology were plasma spraying technique.

Plasma spraying technique for ceramic coating purposes is a versatile process and able to provide high energy and temperature. Alternately, it allows sintering powder with very high melting point such as ceramic powder to be coated in the process[6-8]. Genuinely, this technique consists of plasma torch system and powder feeder system. The major components of gas tunnel plasma torch are anode, cathode, cooling system and gasses supply. Gasses such as argon, nitrogen, and helium effuse from cathode to anode. High voltage difference between electrodes provides very high energy as well as triggers localized ionization in the gas to produce plasma stream. Small atomic size of mono-atomic gasses is used for plasma production due to their low outer electron energy bind. The plasma exits the nozzle as a free or neutral plasma flame. Plasma spraying experiments deployed the gas tunnel plasma torch system [9-11].

Meanwhile, powder feeder is a system used to deliver feedstock powder into the plasma flame for a coating process. Producing better coating performance has taken endless effort from researchers. Many attempts have been made to enhance the efficiency of plasma spraying technique [12]. Other researcher used suspension powder feedstock technique to yield better tribological behaviour in Al_2O_3 coating on steel substrate. The said technique resulted different chemical composition if to be implemented. Khun, Li et al. investigates different particles velocity during spraying process[13]. They discovered higher particle velocity gives significant enhancement in wear and friction of the coating. Plasma spray coating is mainly influenced by the activities happen during in-flight particles in plasma flame [14]; powder with irregular particles shape and size will alter the mechanism of heat transfer. The time taken for in-flight particles in flame before it sintered might be longer or shorter. Other than that, powder clogging that disturbing oxidation and melting activity also causing partially sintered powder that limit the coating quality. Controlling powder flowrate and platting distance is important to overcome the problem.

In this paper, the powder feeder system was modified by designing and fabricating an axial sandblast spray concept to be integrated with plasma torch. The flow consistency of this new system was tested and proven to produce a linear powder output at flowrate 1 L/min to 3.5 L/min whereas the previous system produces a gradually changes of powder output at 2 L/min to 3.5 L/min. To test the compatibility and reliability of the system, two sets of experiment were conducted which are to investigate the correlation between the distance of substrate (2mm to 10mm) and powder flowrate (4 L/min to 5L/min) with the coating thickness as well as surface morphology.

METHODOLOGY

POWDER FEEDER SYSTEM

Literature review been made on previous powder feeder system [11]. Modifications were made on the equipment that gives a high tendency to affect the performances of the system which are nozzle, delivery system and container of the powder feeder system. The powder feeder system was design by using a CAD model using SolidWorks 2017 software and the model were design in 1:1 scale which gives an exact measurement in real size. The new powder feeder system was designed and fabricated based on Product Design Specification (PDS) expectation which to ensure that the subsequent design and product development are meets the need of the user or customer. The PDS considering few factors which they can overcome the backflow of the powder; it is portable systems, environmentally friendly, corrosion resistance and using lighter material.

To test the consistency and reliability of the new powder feeder system, an experiment was conducted to determine the powder output based on flowrate that been set. The container was filled with a 420.3 g of powder and the powder was sprayed on a close container. The powder flowrate was varied from 1 L/min to 3.5 L/min. After 60s, the final weight of the powder was measured again to determine the difference in powder output between initial weight and final weight.

COATING DEPOSITION

As for deposition preparation, the stainless steel (316H) substrate surfaces was grit blasted for cleaning and enhance molecular bonding between the coating and substrate purposes [9]. Surface roughness was measured at 3 different points on each substrate before coating. An average of surface roughness calculated was range from 1.559 µm to 1.727 µm. The powder feedstock used was Sayong ball clay powder with chemical composition (measured by XRF method) which mainly composed of SiO_2 and Al_2O_3as shown in Table 1 [15].

The schematic diagram of the experimental setup is shown in Figure 1. Argon gas (carrier gas) was used for plasma torch which the flowrate was set to 15 L/min. The coating process takes about 30s for each sample and was conducted in atmospheric background. Power input to the plasma was set approximately P = 2.8Kw. Two set of experiment with powder flowrate at 4 L/min and 5 L/min was conducted. The platting distance were varied at L = 2mm, 4mm, 6mm, 8mm and 10mm for each flowrate respectively. The experimental details for plasma spraying of clay powder are as listed in Table 2

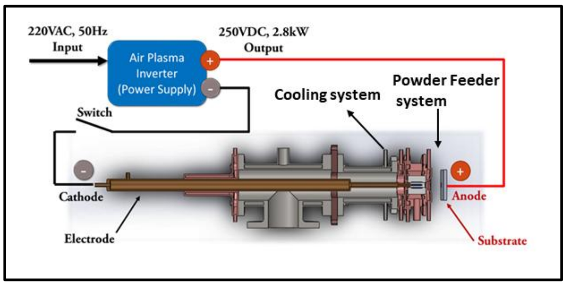


Figure 1: Schematic diagram for gas – tunnel type plasma spraying apparatus used in this research.

Table 1: Chemical Composition (XRF) of clay powder [15]

Composition	*Wt%*
SiO_2	51.28
Al_2O_3	23.78
Na_2O	2.07
K_2O	1.34
MgO	1.48
CaO	0.81
Fe_2O_3	0.46
TiO	0.36
SO_3	0.06
Etc	17.80

Table 2: Experimental condition

Description	Specification
Power Input (kW)	2.8
Working gas argon-Arflowrate (L/min)	15
Spraying distance (mm)	2 - 10
Powder flowrate (L/min)	4 - 5
Coating process (s)	30
Type of powder	Clay powder

Coating Characterization

The measurement of coating thickness and observation of the surface morphology between the substrate and coated layer were done after the coating process by using Optical Microstructure and Scanning Electron Microscope (SEM) respectively. The X – Ray Diffraction (XRD) method was carried out on the surface of the coating to analyze the phases that presences on the coated layer. The scanning range was adjusted from 10° to 90° with a scanning speed of 4.05°/min.

RESULTS AND DISCUSSION

Powder Feeder System

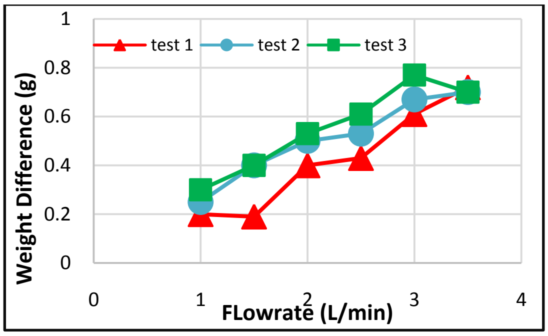


Figure 2: Graph of weight different against flowrate.

Figure2 shows trend of powder spray output increase linearly for flowrate 1 L/min to 3.5 L/min. The graph also shows mass reduction between initial and final powder inside the powder feeder container decrease linearly at average 0.5g to 0.7g.

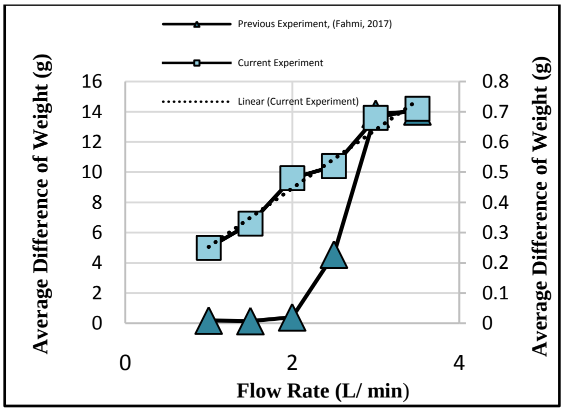


Figure 3: Comparison of powder output between experiments.

Figure 3 shows powder spray output at 2 L/min to 3 L/min from previous system that indicates a drastic change of mass powder output from 4g to 14g. The drastic changes of powder output on previous system were detected due to powder clogging. Our new powder feeder system, have reduced the tendency of powder to be clog on the

Coating Process

Figure 4 shows a different distance of the substrate that was placed which gives a different value of thickness on the coated layer. Furthermore, Figure 4 also shows that by increasing the platting distance of the substrate, the average thickness of the coated layer was also increased with a range from 42.0 µm to 138.5 µm on 4 L/min and from 114.2 µm to 493.9 µm on 5 L/min. On the other hand, by increasing the flowrate of the powder, it will increase the thickness of the coated layer as well. This happened due to coated layer that presence on the substrate were affected by the rate of firing process of the powder which producing an increasing of the coating thickness on substrate surface. Besides, on Figure 4 at the platting distance of 4mm using a flowrate of 4 L/min and 5 L/min shows that the coating process produces the highest average thicknesses which are 317.3 µm and 830 µm respectively compared to the other distance of substrate. This is due to the distance between substrate and plasma flame were very closed which causing the powder undergoing a rapid firing process and causing the powder to melt more and cloth on substrate.

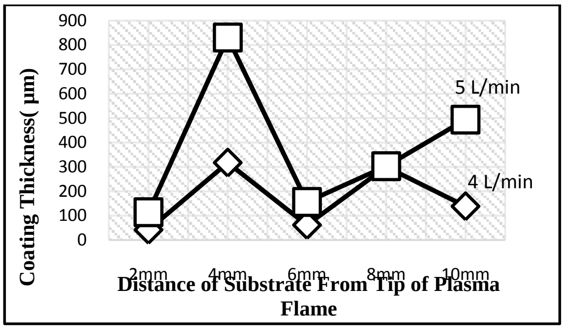


Figure 4: Graph of coating thickness against distance of substrate

The interfacial bonding between coating layer and substrate is observed by using SEM micrograph. Figure 5 shows coated layer produced at platting distance 4mm, have rough coating surface and have low adhesion in interfacial bonding between substrate. These result were differed from the platting distance of substrate from 6mm until 10mm which the coating thickness were increasing linearly as the distance increase at flowrate of 5 L/min as shown in Figure 5. This is due to the flowrate of powder output and distance of substrate reaching the optimum parameter in this coating process. SEM results also shows at platting distance10mm and flowrate 5 L/min, good adhesion of interfacial bonding and smooth surface on the coated layer is produced.

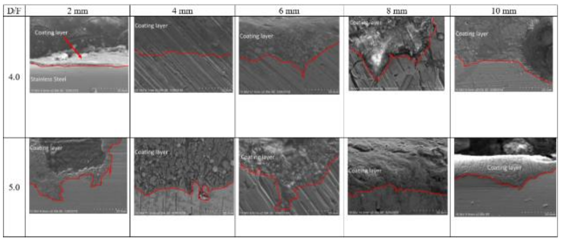


Figure 5: SEM image on cross – section of substrate

On phases identification, the phases that presence on the coated layer are illite (I), albite (A), Kaolinite (K) and quartz (Q). On 4 L/min flowrate of powder, it shows that the intensity of the illite and albite are decrease as the platting distance of the substrate is increase as shown on Figure 6. This happened due to region of flame propagation where the substrate being places will affect the rate of firing process of powder. By observing Figure 6 the substrate was place on the 20,00K of temperature flame which gives unsuccessful fired process that causing only raw material cloth on substrate as shown on Figure 7. Contrary to the distance from 2 mm to 10 mm using a flowrate of 5 L/min on Figure 6 where the illite and albite were change to quartz due to the substrate were placed in a lower temperature region of 17,000K as shown on Figure 7 which gives a successful time and sufficient powder to occur a successful firing process and cloth on the substrate

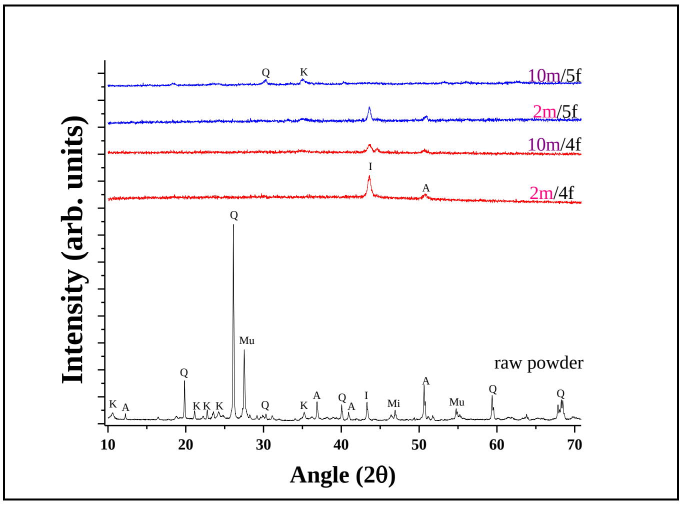


Figure 6: Phases identification on coating layer

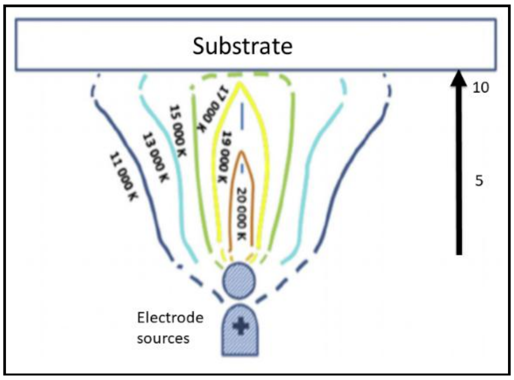


Figure 7: Flame propagation of plasma system [17]

CONCLUSION

The objective and scope of this research were successfully achieved, and the following conclusions were obtained throughout this research:

a) The reliability and compatibility of the new system has achieved whereas the powder flowrate produced a linearity of the powder output from 1 L/min to 3.5 L/min compared to the previous powder feeder system which produced a gradually changes of powder output from 2 L/min to 3.5 L/min.

b) Increasing the platting distance of substrate from 2mm to 10mm and flowrate from 4 L/min to 5 L/min gives an increasing of coating thickness that layered on substrate.
c) Optimum coating parameter for this project were using a distance of substrate of 10mm with flowrate of 5 L/min because it gives a smooth surface and good adhesion of the coated layer based on microstructural observation and have a quartz compound that obtained on the coated layer in XRD analysis.

ACKNOWLEDGMENT

The authors gratefully acknowledge University Teknologi Malaysia (UTM) for provision of research facility and financial support under research university grant (RUG) 16H31 and FRGS 4F808.

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