LOW PRESSURE PLASMA SPRAYING PROCESS - AN ECONOMICAL SUBSTITUTE FOR LABORIOUS, COSTLY PLASMA WELD SURFACING PROCESS FOR HARDFACING CRITICAL COMPONENTS

by

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ABSTRACT

At present critical components like steam turbine spindles and power plant valve components etc. are being handfaced (stellited) using Plasma weld surfacing process involving laborious post weld heat treatment and weld distortion etc. Again, plasma weld surfacing is quite expensive due to deposition of higher build up layer of about 3 to 5 mm of costly consumable (stellite powder). Low pressure Plasma spraying (LPPS) is an economical and productive substitute to conventional weld surfacing process and is being attempted for various critical applications in developed countries. Since LPPS is a new process and the LPPS system (imported equipment cost approx. Rs. 2 Crores) is not available indigenously, WRI is developing this facility to establish the LPPS technology for hard facing applications. This paper describes the new hard facing process, its capabilities, advantages, limitations and industrial applications with respect to conventional plasma weld surfacing and spraying process. The new LPPS facility being developed at WRI has also been discussed.

INTRODUCTION

Plasma arc spraying under normal atmosphere condition has been used for over three decades in applying metals and ceramics for build-up/repair, protection against wear, corrosion and erosion, and thermal barriers. The deposits produced using atmospheric plasma spray process typically contains unmelted particles and oxide inclusions, especially when spraying high melting point and reactive materials. In fact the 'typical' plasma coating is a compromise between porosity levels, percentage of included oxides, angle of powder impact with the substrate, bond strength, thickness limitation and retained stresses. However, the coating works extremely well inspite of all these defects, when the coating properties are matched for their particular applications. During the last two decades, introduction of high power plasma spray gun (approx. 80KW, giving a gas jet velocity of about 600 m/sec and spraying in a controlled atmosphere free of air) have considerably reduced or even eliminated the typical defects found in conventional plasma deposited coating in atmospheric condition. During the last one decade, plasma spraying in controlled atmosphere (more specifically low pressure plasma spraying) has been successfully established in industry for coating the highly stressed or key structural components like gas turbine guide and moving blades etc.

PLASMA SPRAYING IN CONTROLLED ATMOSPHERE

Atmospheric plasma spraying is associated with low substrate bond strength and poor coating quality (presence of oxide inclusion) due to interaction of surrounding air with spray particles and the substrate surface during spraying. To avoid contamination due to surrounding air during spraying and to produce coating with defined properties, additional parameters namely the ambient pressure and the type of ambient atmosphere (inert or reactive can be employed in the plasma spraying. At the present time, the following variants on the process are established or are under developments [1,2].

a) Vacuum Plasma Spraying (VPS) - ambient pressure between 20 and 700 torr, inert atmosphere. This is also called as Low Pressure Plasma Spraying (LPPS).

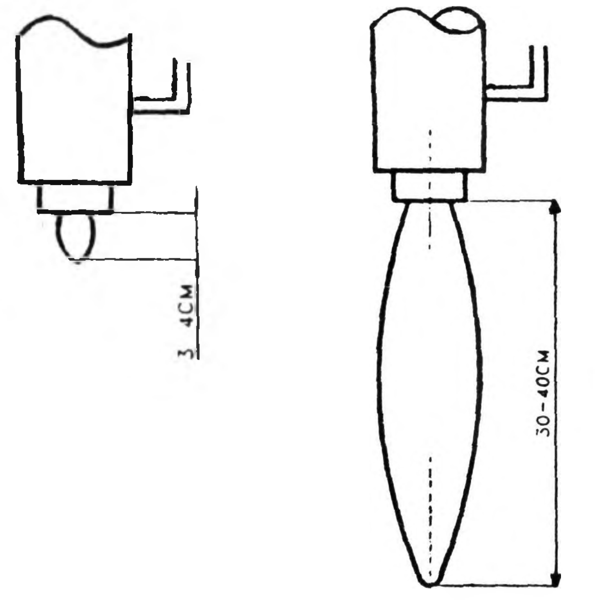
b) Reactive spraying in vacuum - ambient pressure between 20 and 700 torr, reactive atmosphere like N_2 or methane.

c) Plasma spraying at elevated ambient pressure - ambient pressure between 1 and 2 bars, inert or reactive atmosphere.

Plasma spraying at ambient pressure between 20 and 700 torr (ie. below atmospheric pressure) is preferred in most of the cases because the plasma gas jet velocity can be increased economically up to Mach 3 even with relatively low plasma torch power of 80 KW. Higher plasma gas velocity ensures better adhesive strength and more homogeneous chemically pure (due to less harmful gas-metal reaction) coating even with reactive spray materials. Plasma spraying at ambient pressure below atmosphere in inert atmosphere has already been established world wide for certain specific applications. The plasma spraying at increased ambient pressure (above atmospheric pressure) is currently still in an early stage of development and has still not found commercial application. High melting materials such as B_4C can be sprayed with a higher degree of coating efficiency with higher process pressures (above 1 atmosphere) due to reduced spray particle velocity at higher pressure [2].

LOW PRESSURE PLASMA SPRAYING OR VACUUM PLASMA SPRAYING

In Vacuum Plasma Spraying (VPS) or Low Pressure Plasma Spraying (LPPS) process, the work piece and the plasma spraying torch with powder port are enclosed in a vacuum chamber which is kept under a constant (adjustable) soft vacuum (20 to 700 torr). Therefore, preheat, spray as well as post heat-treatment are carried out in an inert atmosphere at low pressure. At a soft vacuum level, the plasma jet elongates to about 30 to 40cm (as compared to 4 to 5cm in case of normal atmospheric spraying) and approaches a seemingly laminar flow configuration Fig. 1. The length and degree of turbulence at the boundary of the jet are a function of vacuum level in



a) 760 TORR b) 70 TORR

Fig. 1 : Formation of Plasma Jet

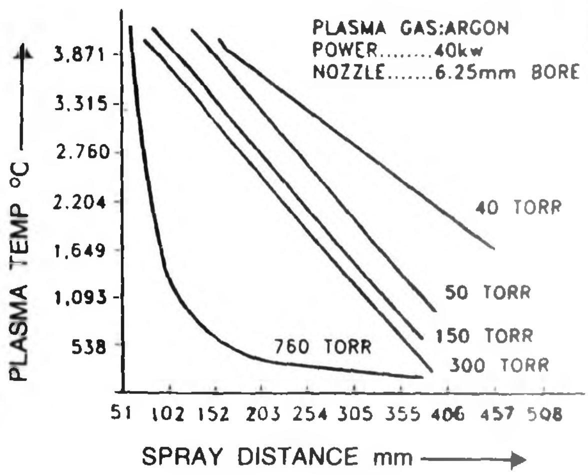


Fig. 2 : Plasma Temperature Vs Spray Distance at different Pressure Levels

the spraying chamber during spraying. In one particular case, when the chamber pressure alone was vaned from 20 to 80 torr, the plasma flame length varied from 500 mm to 200 mm. The effect of other operating parameter variations ware found relatively less on flame length variation [3]. The extended plasma flame provides a longer heating zone (permitting increased dwell time with thorough and efficient particle melting) and lower turbulence at the boundary of the jet tending to maintain and not dissipate its energy level quickly as under atmospheric condition.

Under soft vacuum conditions, turbulence is minimized with corresponding retention of plasma temperature even at a larger distance from the nozzle [4]. From **Fig. 2** it is seen that at a pressure level of 50° torr and a 300 mm spray distance, the centre line temperature of a 40KW input plasma flame is about 1900°C Vs 260°C at atmospheric pressure level.

Due to the low pressure in the working chamber the plasma gas jet velocity can be increased up to Mach 3, which means that the material being sprayed is also discharged at a higher velocity. Particles with a high degree of kinetic energy give coating with good adhesion and few pores. However, to spray materials with a high melting point, sometime LPPS equipments are designed for arc powers upto 120 KW. But in general, additional energy for proper melting of spray material is supplied by transferred arc between the nozzle of spray gun and the work piece. In addition to supply additional energy for melting the particles, transferred arc is used for cleaning of the surface to be coated and for intensive and rapid preheating of the work piece prior to actual spraying inside the chamber itself.

ADVANTAGES OF LOW PRESSURE PLASMA SPRAYING PROCESS

The advantages of plasma spraying in low pressure inert environment with respect to atmosphere plasma spraying have been found as follows :

- Higher bond strength - because of higher gas particulate velocity (upto Mach 3) and higher substrate preheat and operating temperature without detrimental nitride formation and oxidation of coating and substrate during spraying.
- Reduction/elimination of oxide inclusions especially with reactive materials.
- Minimal changes in chemistry and metallurgy between powder and coating due to no gas metal reaction.
- High as-coated density (upto 99.5%) because of very low porosity.
- Excellent dimensional thickness control due to large spray patterns/distances which simplify coating large parts with varying profile.
- Spraying efficiency and quality is less sensitive to slight variation of spraying distance because of a longer heating zone maintained at relatively higher temperature (permitting increased dwell time for efficient particle melting) and lower turbulence at the boundary of the plasma jet. Suitable for objects with varying profiles like gas turbine blades etc.
- Higher job temperature kept during spraying ensure reduced internal stress in coating because molten particles do not solidify rapidly by quenching on impact, rather they stay molten longer and flow to fill irregularities on the substrate surface [4].
- By keeping the substrate at high temperature for the complete spray cycle, the coating begins to recrystallies, loosing its characteristics lamellar structure and coating/substrate diffusion begins enhancing the bond strength further [4].

APPLICATION OF LOW PRESSURE PLASMA SPRAYING PROCESS

When compared to other sophisticated coatings process, such as electrolytic plating, physical and chemical vapour deposition and weld overlay etc., it is clear that LPPS provides a much faster rate of deposition for critical applications. To date, this process has become established worldwide in the turbine industry for MCrAlY (M = Co, Ni or thier combinations) type coatings for protection against hot gas corrosion and oxidation for turbine aerofoils, blade tips and shroud segments. It is expected that LPPS coatings technique will be adopted in other areas also due to its special features and associated benefits over other processes.

Spraying of complicated materials composition such as a mixture of Mo/Mo_2C (vulnerable to oxidation losses) has been carried out successfully using LPPS process and the resultant coating composed of ductile Mo matrix, the eutectic alloy Mo/Mo_2C and pure Mo_2C has exhibited great resistance to wear with reduced sliding friction [5].

Under low pressure condition, reactive material like titanium can be sprayed with a high degree of purity. Pore-free coatings cannot be obtained, but the pores occuring can be regarded as negligible for the purposes of corrosion prevention [5]. The structure typical of sprayed titanium coating, is completely absent in LPPS sprayed coating. Only small pores (dia-0.01 mm) can be detected. Near adhesive planes pores are more evident, although they are not connected to other pores.

The conductive coating produced using atmospheric plasma spraying process is associated with oxide inclusions and needs a post reducing annealing under Hydrogen which generally increases cost and decreases the deposit bond strength. Again the high temperatures involved during annealing (600°-800°C) limit the available substrate materials. LPPS can be used to deposit such conductive coatings with higher bond strength and very low oxides directly on the substrate without a post thermal treatment. During application of LPPS process for production of Hybrid micro-electronic components test samples, the copper and aluminium coating sprayed on the alumina and silica substrates exhibits a bond strength of several Kg/mm^2 (2.5 Kg/mm^2), an average surface roughness of 1μ CLA and low resistivity [6]. One new and very rewarding application of LPPS spraying is the manufacture of sputter targets of complex geometries (made of reactive materials like Cr, Ti, Mo or W) free from pores and oxides inclusions, mainly for electronic industry [2].

Super alloy such as, stellites and Hastelloys etc., which typically deposit as poor quality plasma coatings when sprayed under atmospheric conditions, can now be vacuum plasma sprayed to get quality similar to weld overlay deposits. For instance, a stellite type coating produced using LPPS process has a fully dense structure without oxides and an uninterrupted diffused interfaced bond. The specimen was preheated and post spray heat treated in situ inside the spray chamber to achieve this structure [4].

Tungsten carbide with 12% to 17% cobalt binder) and chromium carbide (with nichrome binder) coatings show exceptional improvement when vacuum plasma sprayed. This coatings are extensively used in gas turbine engines for resistance to abrasive wear and fretting corrosion. Under atmospheric spray conditions, decarbonization reduces the hardness of carbides and nichrome binder begins to oxidise. Both conditions reduces high temperature wear resistance as compared to vacuum sprayed condition.

LPPS FACILITY BEING DEVELOPED AT WRI, INDIA

LPPS facility being developed at WRI is mainly for hardfacing relatively simple configuration jobs like steam turbine cylindrical spindles (length upto 1200mm), valve wedges and seat rings etc. At present these components are being stellited using laborious plasma tranferred arc surfacing process. In general the basic system components are similar to conventional LPPS facility available worldwide. **Fig. 3** shows the schematic arrangement of the complete LPPS facility being developed at WRI. The double wall water cooled spray chamber is rectangular in shape and size

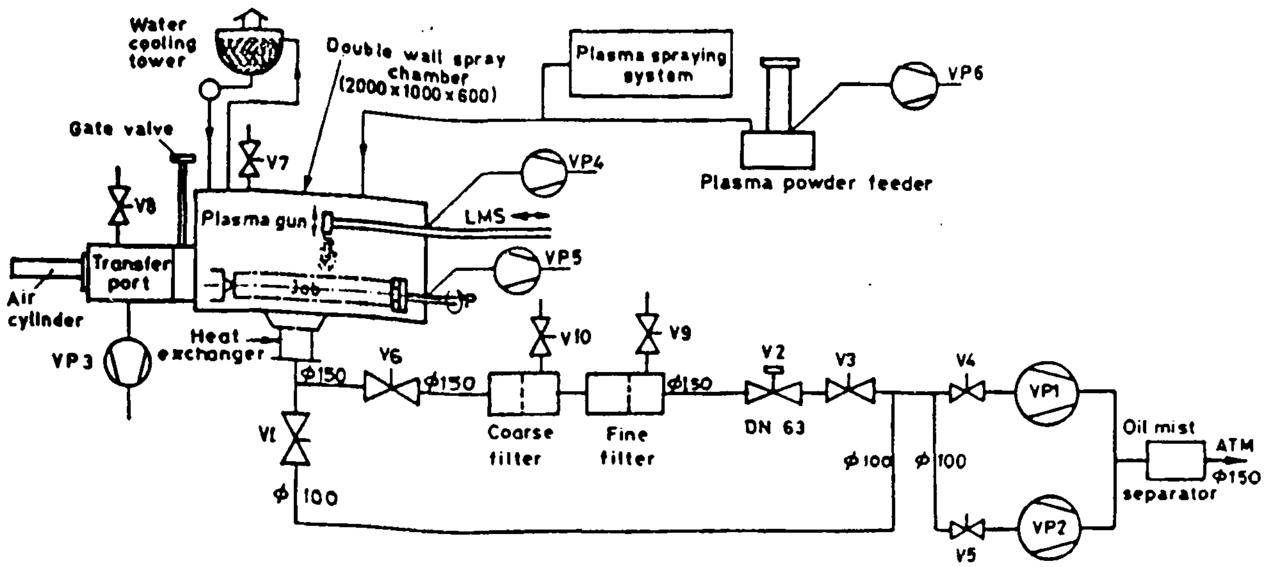


Fig. 3 : Schematic layout of LPPS System being developed at WRI

of 2000x1000x600mm. The job is held and rotated between head stock of job positioner and rotating centre. The plasma spray torch is moved linearly parallel to job axis. The job to torch distance can be adjusted in a mechanised way from outside the spray chamber during spraying. The hot plasma gas loaded with fine spray powder particles is cooled in heat exchanger and cleaned off the spray particles dust using cyclone separator and a fine filter before being evacuated by two 5000 LPM capacity rotary vacuum pumps. The water cooled transfer port has been connected to main LPPS chamber thro-mneumatic operated gate valve to take up small size test samples and batch production of small size valve seat rings.

For fast evacuation of transfer port one 1000 LPL capacity single stage rotary vacuum pump has been provided. Special plasma toch 'FA-VB', and powder feeder '10-Compact' procured from Switzerland have been interfaced with the basic 45 KW plasma spraying system available at WRI. Suitable vacuum measuring and controlling system has been procured through M/s. Plasma Technik AG to ensure proper vacuum level control within ± 1 torr of set value during spraying. The complete LPPS operation will be sequenced through PLC system. The LPPS facility at WRI is in assembly stage and actual spraying trials on test samples to establish LPPS technology will be taken up in near future.

CONCLUSION

Low Pressure Plasma Spraying (LPPS) process has been increasingly accepted as an effective coating process to form a non-contaminated dense coating having good bond strength. Plasma spraying under vacuum largely avoids gas/metal reactions during coating, so that oxide free coatings can be produced, even for reactive materials. Preheating, surface cleaning and post heating are possible using transferred arc inside the chamber to enhance the quality of coating LPPS has already been established worldwide for hardfacing gas turbine blades and in other areas also it is slowly finding place.

At Welding Research Institute, India, LPPS facility is being designed and developed for hard facing relatively simple configuration components like steam turbine spindles, valve gate and wedge etc. At present these components are being hardfaced (stellited) in India using transferred arc process.

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