Coatings Applied by High Enthalpy Plasma Spraying with Axial Feed

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A novel plasma spraying technology is described. By feeding the powder axially into a high enthalpy plasma plume, significantly higher spray rates and deposit efficiency are achieved, leading to improved economics of the spray process. Hard chrome replacement, wear resistant, corrosion resistant as well as thermal barrier coatings deposited by axial feed plasma are presented and discussed.

Although plasma spray equipment has been used to deposit coatings for many years now, plasma gun design has remained relatively unchanged. One of the greatest shortcomings of conventional plasma is the arc instability leading to difficulties to control coating quality and resulting in low deposit efficiency, i.e. for every pound of powder fed into the gun, only a small portion ends up as coating on the part. Traditional plasma guns spray many materials with low spray rates at deposit efficiency sometimes considerably less than 50%. Many of the low deposit efficiency materials are also sometimes the most expensive. Since the materials represent the largest single factor in the total cost for any plasma coating, low deposit efficiency is a serious process deficiency.

For many of the past years, plasma spray technology was driven by aerospace applications, primarily for jet engine components, and process cost was secondary to coating performance. Since then, competition has forced even the aircraft engine manufacturers to become extremely cost conscientious. More importantly, the use of plasma spray coatings is now much more widespread and new applications are often limited only by cost. Productivity and cost are very important issues for all manufacturing operations, so improvement of plasma spray efficiency is now a critical need. Strict quality control procedures require regular laboratory testing to confirm equipment performance. This can add to the cost as well as reduce overall productivity. Therefore, improved plasma spray process stability and reproducibility are today's stringent needs.

The High Enthalpy plasma technology offers a high degree of process stability and improved coatings reproducibility, combined with high spray rates and high deposit efficiency. These features create the conditions for an increase in productivity of up to three to five times and a reduction of coating cost with as much as 50%. In addition, superior quality coatings can be easily applied industrially and novel coatings can be researched and developed in the laboratory.

Four major conceptual features characterize traditional plasma technology:

1. The electric arc root is not stabilized, i.e. the anodic root fluctuates axially and also works in arc re-strike mode [1]
2. The anode electrode is the same with the barrel of the gun
3. The operating arc voltage is relatively low and usually drops in time with electrode wear [3], [4].
4. The powder injection takes place relatively close to the arc root resulting in a turbulent and often-unpredictable interactions between the powder feed flow and the arc.

These features concur to reduce the overall efficiency of the spray process.

It is known that the anode attachment of the electric arc root is a highly turbulent phenomenon when hundreds of amps discharge into a "hot spot" localized on the surface of the anode. Since the anode is also the gun barrel, the injection of the powder takes place in the proximity of the arc root attachment, often resulting in an interference between the plasma turbulence created by the arc root and the powder flow.

The random movement of the arc root due to axial fluctuations and the arc re-strike combine to affect negatively the stability and uniformity of the spray process and the resulting coating properties [2]. Arc re-strike itself is a highly detrimental phenomenon. The re-strike of the arc root creates repetitive moments of virtual plume shrinkage [1] with adverse effects on particle melting, trajectory and velocity.

More recently, there have been attempts to correct some features of the traditional plasma technology. However, these have resulted in somehow complicated designs with as many as three sets of cathode electrodes being operated simultaneously inside the plasma gun [5], [6], [7].

The High Enthalpy plasma technology (Fig.1) resolves the shortcomings of the traditional plasma by acting in several important ways:

1. The electric arc root is stabilized and the arc re-strike is practically eliminated [8].
2. The anode is separated from the gun nozzle (barrel) [8].
3. The gun operates at significantly higher voltages [8].
4. The powder feed flow is optimized for different spray applications by injection either radially [9] or axially [10] as well as simultaneously whenever desired.
5. Only one cathode electrode is used in the plasma gun [8]

By using a proven and patented plasmatron design [8], the arc is elongated and its root is stabilized into the bore of a long life anode electrode (Fig. 1). The anode electrode also provides for a diffusion of the arc root without generating stationary surface “hot spots” The gun nozzle (barrel) and the powder injection port are separated from the anode electrode [8], [9], [10].

This new plasma technology concept achieves the following:

1. By stabilizing the arc root and by eliminating the arc re-strike, a constant voltage arc and a stationary and uniform plasma are generated. By diffusing the arc root and by working with higher voltage-lower amperage arcs, the electrodes wear is reduced and the long-term process stability is highly improved. By separating the anode from the gun nozzle and the powder injection, the turbulent interaction between the arc root phenomena and the powder feed flow are practically eliminated. This results in increased powder entrainment and less air entrapment in the plume.
2. By stabilizing the arc length and the axial fluctuations of the arc root, a constant and stable voltage is generated. Typical arc voltages for High Enthalpy plasma are between 200-250V depending on the specific spray parameters. These higher voltages induce increased ionization and higher plasma enthalpy. By working with ternary plasma gas mixtures such as Ar+N2+H2 (He), combined with the high arc voltages, an elongated plasma plume is generated having enhanced heat capacity and thermal conductivity. These features translate in substantially higher spray rates and deposit efficiency.
3. Powder injection is an important step in plasma spraying. High Enthalpy plasma can work in both powder injection modes i.e. axial and /or radial therefore maximizing the spray output for the entire range of powder materials.
4. By using only one gas cooled tungsten cathode the High Enthalpy plasma becomes uncomplicated and reliable.

Due to the use of a stabilized plasmatron technology, the high enthalpy plasma gun can be operated at flexible power levels of up to 100 kW, thus covering all foreseeable industrial needs.

The High Enthalpy plasma offers new opportunities for increased productivity, reduced coating costs and increased reliability. The increase in spray rates can reach a factor of three to five. The higher deposit efficiency means coating cost savings through less powder wastage. Due to better melting and higher gas velocity, the high enthalpy plasma produces coatings with superior properties, which can be deposited at high spray rates. Examples are: dense and hard carbides (Fig.2), very low porosity chromium oxide (Fig.3), advanced chromium replacement coatings (Fig.4), high integrity abradables (Fig.5), advanced TBC’s (Fig.6) etc.

Conclusions

High enthalpy plasma represents an important step forward in thermal spray technology that offers many significant advantages such as:

- Increased deposit efficiency leading to substantial cost savings. Many coating materials show increases of 30-40%.

- Better heating, melting and protection of the powder particles in the plasma, leading to improved coating quality (lower porosity and less un-melted particle content). It also reduces the oxide content in metallic coatings.

- Higher spray rates whenever desired. Most materials can be sprayed at rates of at least double the normal rates with the accompanying increases in productivity.

- Permits nozzle designs that maximize plasma spray output and coating performance.

- Permits advanced coatings development such as: high production abradable coatings, advanced thermal barriers, dense metallic and carbide coatings, production of nano-materials and nano-coatings, production of FGM's, mixed and multi-layer coatings, MMC's etc.

References

1. M. Boulos, E. Pfender, P. Fauchais, *Advances In Thermal Spraying Short Course*, NTSC'93, Anaheim, CA (1993)
2. J. Schein, Z. Duan, J. Heberlein, *Diagnostics of Arc Dynamics in Plasma Spray, Proc. GEC'98 Meeting of The American Physical Society* (1998)
3. L. Leblanc, C. Moreau, *Study on the long-term stability of plasma spraying, ITSC'2000, Montreal, Canada* (2000)
4. L. Leblanc, C. Moreau, P. Gougeon, *Long-term stability of plasma spraying: study on the evolution of the in-flight particle state, coating microstructure, voltage and acoustic signatures, United Thermal Spray Conference, Dusseldorf, Germany* (1999)
5. G. Barbezat, K. Landes, *Plasma Technology TRIPLEX for the Deposition of Ceramic Coatings in the Industry", ITSC'2000, Montreal, Canada* (2000)
6. K. Landes; *US Patent Nr. 5,332,885*
7. N.W. Mettech Corp., *Axial III" commercial brochure* (2000)
8. L. B. Delcea; *US Patent Nr. 6,114,649*
9. L. B. Delcea, *U.S. patents pending*
10. L. B. Delcea, *U.S. patents pending*

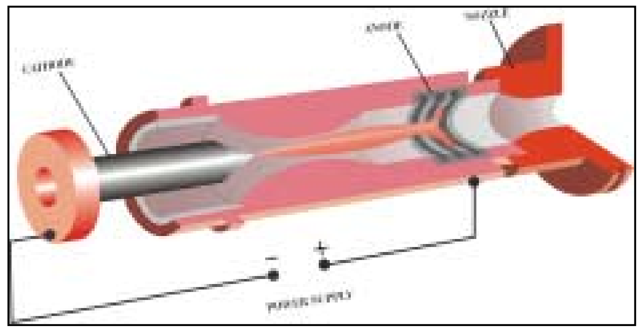

Fig. 1: Principles of the High Enthalpy plasma technology

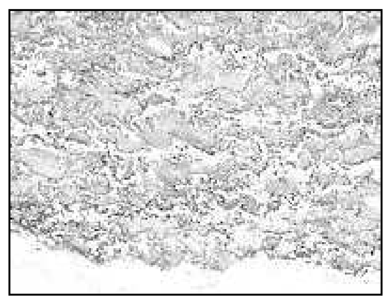

Fig. 2: Tungsten carbide coating

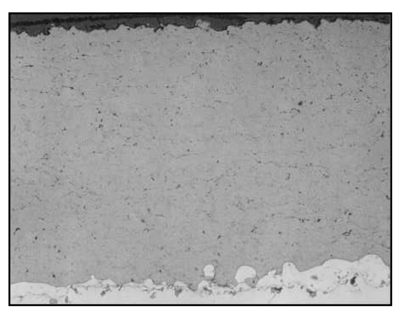

Fig. 3: Chromium oxide coating

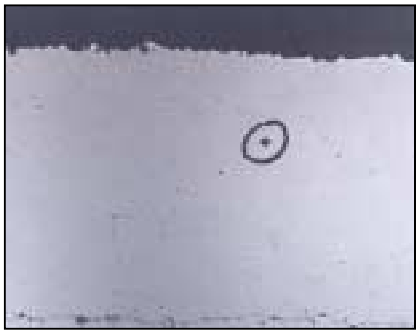

Fig. 4 Hard Chromium replacement coating

Fig. 5 Al-Si/ Polyester abradable coating

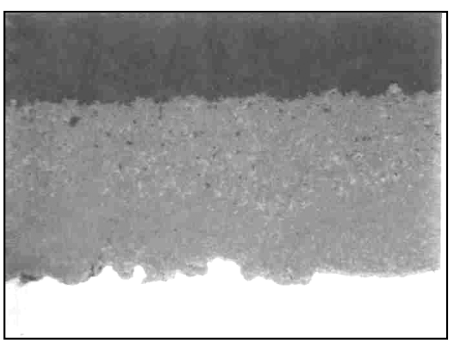

Fig. 6 Dense YSZ thermal barrier coating

Fig. 7 General view of the High Enthalpy plasma spray gun