Design of High Efficiency Hypersonic Plasma Spraying System and Characteristics of Its Ceramic Coatings

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Abstract

A novel high efficiency advanced hypersonic plasma spraying system is invented at power level around 60 kW, at which gas and particle velocities of 2400 and 600 m/s can be achieved respectively. This paper deals with the high efficiency hypersonic plasma spraying system design, the structure of the hypersonic plasma gun includes the special Laval nozzle as the single anode, inner powder supply, cooling circle and lower flow gas supply, and the mechanisms of hypersonic plasma jet as well as the effects on the sprayed particle. The spraying process parameters of several ceramic powders such as Al_2O_3, Cr_2O_3, ZrO_2, Cr_3C_2 and Co-WC were optimised. The properties and microstructure of the sprayed ceramic coatings were investigated. For Al_2O_3 coating, porosity<1%, microhardness-HV1357 and bond strength-51MPa were achieved. Nano Al_2O_3-TiO_2 ceramic coating sprayed by using the high efficiency hypersonic plasma spraying was also studied. High efficiency hypersonic plasma spraying improves greatly the ceramic coatings quality compared with the conventional air plasma spraying (Metco 9M), as well as it has lower energy and gas exhaustion compared with the high power hypersonic plasma spraying (Plazjet), which can spray wear resistant ceramic coatings with high quality but low cost.

Keywords: *High Efficiency, Hypersonic, Plasma Spraying, Ceramic Coatings*

1. Introduction

Plasma spraying is a promising technology to produce the high performance ceramic coatings. Plasma sprayed coating quality depends upon the velocity and melting state of the particles at the moment they impact the substrate to be coated[1]. The melting condition and velocity of the sprayed particles depend upon the exit enthalpy and velocity of the plasma jet, and the time that the particles remain within the plasma jet.
Unfortunately, conversational air plasma spraying ceramic coatings quality is to be improved for some high-tech applications. The gas velocities of 300-800 m/s and particles velocities in the range of 130-220 m/s were obtained for conventional plasma guns with 5-8 mm diameter nozzles and 50-75 l/min total gas flow rates[2]. Additionally, the disordered plasma jet generated by conventional plasma gun has a "boundary effect". As the distance from the nozzle exit increases, the enthalpy decreases and the air content drawn into the jet increases rapidly. The distribution of temperature, velocity and oxygen content in cross section of the jet are uneven. Thus the melting state, velocity and oxidation extent of the being sprayed particles near the border of the jet are out of condition compared with which in the centre. Consequently, conventional air plasma spraying has limited coating quality with low bond strength and high porosity, especially for ceramic coatings with high melting points.
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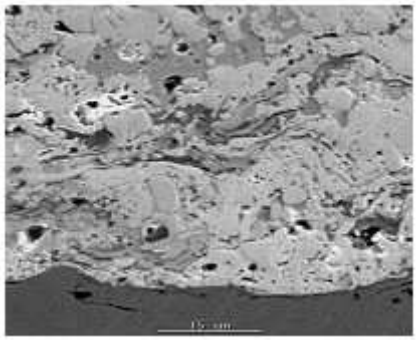
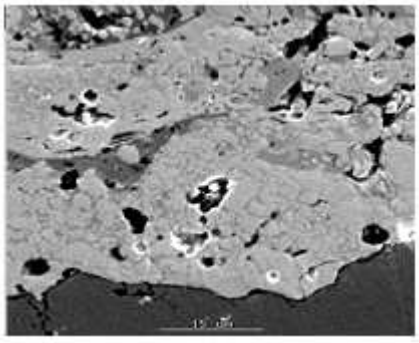


a) High efficiency hypersonic plasma coating



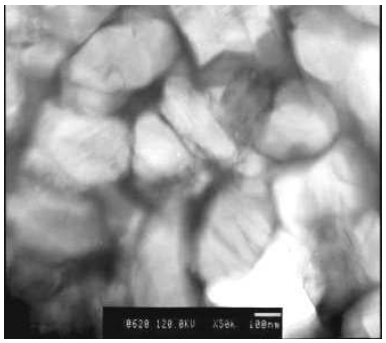
(b) Metco 9M coating

Figure 9 *SEM of 12Co-WC coating X1500*

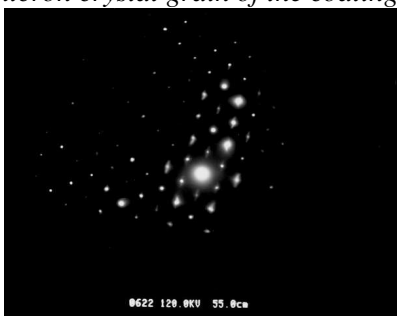
The high efficiency hypersonic plasma sprayed ceramic coatings possess much denser and more uniform microstructure than conventional plasma sprayed coating. This is the main reason why it achieved the improvement in coatings quality.

5. Nano-Al_2O_3/TiO_2 Ceramic Coating

Figure 10 shows the coating's TEM pictures of high efficiency hypersonic plasma sprayed nano-Al_2O_3/TiO_2 ceramic powder, it can be seen that the coating consists of submicron crystal grain (grain size as 200~300nm) and nanometer crystal grain (grain size less than 50nm).

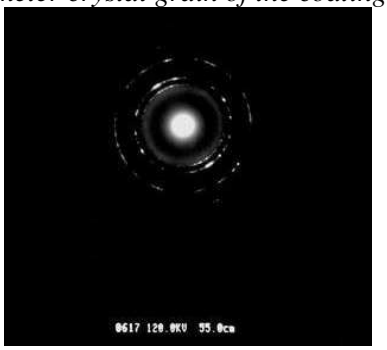


a) Submicron crystal grain of the coating



b) Selected area electron diffraction (SAD) pattern

c) Nanometer crystal grain of the coating (DF)



d) Selected area electron diffraction (SAD) pattern

Figure 10 *TEM of Nano-Al_2O_3/TiO_2 Coating*

Further XRD analysis as shown in figure 11, the coating is composed of α-Al_2O_3□brookite TiO_2 and γ-Al_2O_3, as well as the diffraction peaks of brookite TiO_2 andγ-Al_2O_3 are wider, which means amorphous phases exist in the sprayed coating.

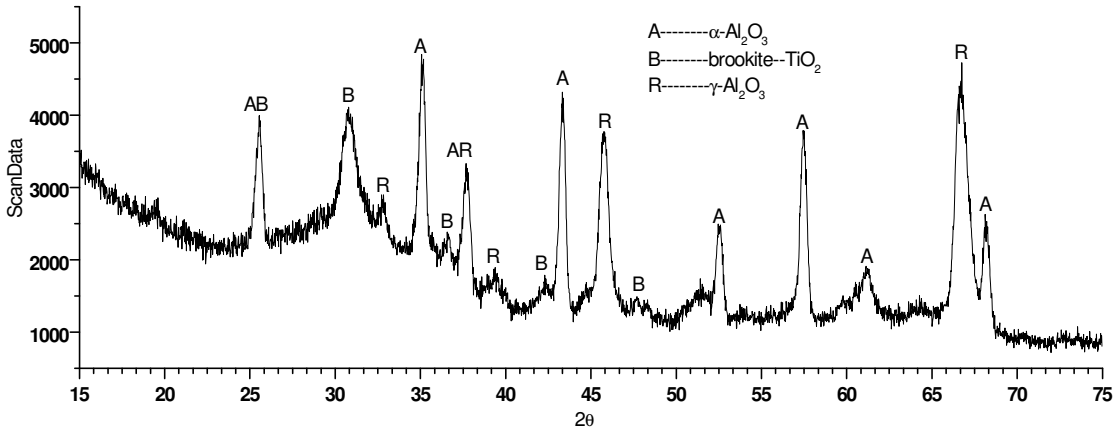


Figure 11 *XRD of Nano-Al_2O_3/TiO_2 Coating*

6. Cost Analysis

Comparison of the consumables and operating costs of high efficiency hypersonic plasma spray with Plazjet is shown in Table 2. The consumables are much less and energy saved for high efficiency hypersonic plasma spray. So it costs only one half of the PlazJet while with the same coatings quality. This is why it is called as "high efficiency".

Items		PlazJet	High efficiency hypersonic plasma spray
Primary gas flow (m^3h^{-1})	Ar	□	3.8
	N_2	15.8	□
Secondary gas flow (m^3h^{-1})	H_2	6.5	0.26
Power (kW)		210	64
Powder supply (kgh^{-1})		5.4	2.4
Deposition efficiency (%)		29	36
Costs of 1kg Al_2O_3 coating (China ¥)		516	265

Table 2 *Comparison of the Consumables and Operating Costs of High Efficiency Hypersonic Plasma Spray with Plazjet*