CHAPTER VIII
SUMMARY

In the present investigation, a detailed study on the characterization of the plasma spray torch and the injected particle behavior in a thermal plasma was made.

A. Characterization of the plasma torch

Electrothermal efficiency and plasma jet parameters

A non-transferred plasma spray torch was characterized. A theoretical calculation was made for the electrothermal efficiency in a DC plasma spray torch operating at atmospheric pressure with power level in the range from 2.6 to 20 kW using energy balance equations. Argon and argon +10 % nitrogen mixture were the plasma forming gases. In all the calculations the experimental values of the parameters were used. The calculated efficiency ranged from 59 to 65 %. Efficiency was found to increase with addition of nitrogen. The overall energy balance calculations showed that the heat transfer to the plasma-forming gas decreased with increase in arc current and the same was more significant at higher flow rates.

Anode for a non-transferred DC plasma spray torch was designed to improve electrothermal efficiency. ANOVA for the two level factorial design was made. Plasma gas flow rate, current intensity, nozzle diameter and length were found to influence the efficiency.

Plasma jet velocity for different flow rates, input to the torch and nozzle dimensions were calculated from the gas enthalpy. It was found that the velocity increased with increase in the power input to the torch and gas flow rate and decreased with increase in nozzle length and diameter. The temperature, thrust, density and the
degree of ionization of the plasma jet were also calculated from the thermofluid
dynamical method. The temperature and the degree of ionization were found to be in the
range from 1,400 to 4,800 K and from $5 \times 10^3$ to $44 \times 10^3$ respectively. Average electrical
conductivity of the plasma jet at the nozzle was calculated from the arc characteristics.

I-V Characteristics of the plasma torch

I-V characteristics of a non-transferred dc plasma spray torch operating on argon
and argon + nitrogen mixtures as plasma forming gases are reported. Arc voltage is
decreased with increase in arc current and increased with increase in electrode gap.
Arc power is higher at higher percentage of nitrogen in argon. Nottingham co-efficients
were calculated using numerical method.

An attempt was made to develop an empirical relation for the arc voltage in
relation to arc current and gas flow rate. Current–voltage characteristics of a non-transferred
plasma torch operating with argon and argon + nitrogen mixture were studied. The net power
transferred to the plasma increased with an increase of the gas flow rate. The increase was
12.83 and 15.53 % respectively for arc currents of 212.5 and 312.5 A, for an increase of the
argon gas flow rate from 20 to 30 l min$^{-1}$. Also the addition of nitrogen gas with argon
increased the arc power. Arc voltages were experimentally measured and they are in good
agreement with the values calculated using the empirical relation developed.

B. Injected particle behavior

Heat transfer between a thermal plasma and a particle injected into it, with
emphasis on the effects which the evaporation of the latter imposes on heat transfer from
the former was reported. The investigation was done by numerical methods. The results
referred mainly to atmospheric-pressure argon plasma. As a comparison, nitrogen plasma
was considered in the temperature range from 3,000 to 25,000 K. Interaction of plasma with alumina and tungsten particles were considered. Evaporation severely reduced heat transfer to a particle and, in general, this effect was more pronounced for materials with low latent heat of vaporization. The conductive heat transfer from plasma (Ar, N₂, Ar+H₂) to a particle of diameter 100 μm was calculated and compared with the radiative heat loss from the particle. The results of a relatively simple analysis showed that except for a particle with a surface temperature above 2,100 K immersed in an argon or a nitrogen plasma below 4,100 K, radiation heat losses from the particle to the surroundings were negligible compared to the conductive heat flux from plasma to the particle. The minimum value of plasma temperature for a particle to attain boiling point was calculated. The calculated results for the lowest value of plasma temperature for the three materials (alumina, tungsten, and graphite) and four plasmas (Ar, N₂, H₂, Ar+H₂) have been reported. The plasma temperature is higher for higher boiling point materials and lower for higher enthalpy plasmas.

A new approach to study the particle velocity and residence time in a thermal plasma in relation to input parameters (power, gas flow rate, injection velocity of the particle and particle size) and nozzle dimensions (nozzle length and diameter) has been made. Injected particle’s temperature and thermal history were calculated for particles of three different materials (alumina, tungsten and graphite) in argon plasma. Heat transfer per particle injected in to the plasma and liquid fraction of the particle after it reached the melting point are reported. Particle velocity is found to increase with increase in power, gas flow rate and injection velocity and decrease with increase in particle size, nozzle length and nozzle diameter.
Thermal histories of the particles in relation to the plasma temperature and particle diameter are presented. Particle's residence time is found to increase with increase in diameter of the particle. Allowable powder feed rate for complete melting of the particle is higher at higher percentage utilization of the plasma power. Powder feed rate is seen to decrease with increase in particle size and it is higher for tungsten and lower for graphite particle. The results of the study will be useful in the application of plasma spray torches to obtain high quality coatings on substrates.