Question:- Explain the mechanism of power attenuation in laser surface cladding and derive a formulation for power attenuation for a Gaussian beam. Also explain the heat partition for a ray incident at an angle of 45^o.

The proposed solution is for uniform, Gaussian will have to be accounted for in Eq. (1.2) How??? (Think!!!!)

Due to presence of powder particles in the path of laser beam, there is power attenuation. The beam is assumed to be uniform (Gaussian distribution is not considered explicitly). The powder delivery is co-axial.

Laser power absorption can be attributed to following phenomena (figure 1):

1) Laser beam power reaching directly to the substrate (P_1)
2) Pre-heating of powder particles entering the beam (P_2)
3) Fraction of laser beam reaching directly to the substrate gets reflected and comes in contact with the powder particles, and fraction of that will get absorbed (P_3)

$$P_1 = \beta_{substrate} \times P_{laser} \times (1 - \frac{P_{att}}{P_{laser}}) \qquad (1.1)$$

where $\beta_{substrate}$= absorptivity of substrate

Assuming that inter-particle shadowing is negligible $\frac{P_{att}}{P_{laser}}$ can be approximated as ratio of projected area of powder particles to the laser beam area. (Due to the fact that volume fraction of particles in powder jet usually smaller than 1 %)

Mass flow rate of powder ($\dot{m}_p$)is given by,

$$\dot{m}_p = n\, \rho v_p \frac{4}{3} \pi r_p^3$$

where n = no. of particles/length, ρ = density of clad particle, v_p = particle velocity, r_p = radius of the particle.

Number of particles per unit length (n)

Length travelled by particles across beam

Projected area of particle/ Area of laser

$$\frac{P_{att}}{P_{laser}} = \left[\frac{\dot{m}_p}{\rho v_p \frac{4}{3}\pi r_p^3}\right] \times \left[\frac{2r_l}{\cos\theta_{jet}}\right] \times [\frac{\pi r_p^2}{\pi r_l^2}] \quad (1.2)$$

$$\frac{P_{att}}{P_{laser}} = \frac{3}{\pi} \times \frac{\dot{m}_p}{2\rho r_l r_p v_p \cos\theta_{jet}} \approx \frac{\dot{m}_p}{2\rho r_l r_p v_p \cos\theta_{jet}} \quad (1.3)$$

where r_l = radius of the laser beam (assumed to be constant), θ_{jet}= angle of powder delivery and laser for co-axial.

Assuming two cases of radius of jet (r_j)

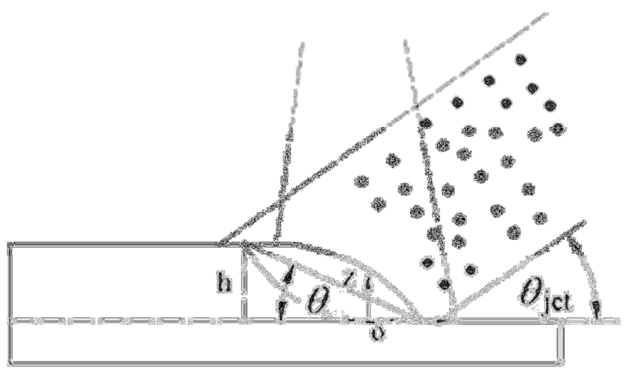

Figure 1: Laser Beam Shadowing by powder particles

$$\frac{P_{att}}{P_{laser}} = \frac{\dot{m}_p}{2\rho r_l r_p v_p \cos\theta_{jet}}, if\ r_{jet} < r_l$$
$$= \frac{\dot{m}_p}{2\rho r_{jet} r_p v_p \cos\theta_{jet}}, if\ r_{jet} \geq r_l \quad (1.4)$$

$$P_2 = \beta_p \times P_{laser} \times \frac{P_{att}}{P_{laser}} \quad (1.5)$$

$$P_3 = \beta_p \times (1 - \beta_{substrate}) \times P_{laser} \times (1 - \frac{P_{att}}{P_{laser}}) \frac{P_{att}}{P_{laser}} \quad (1.6)$$

where β_p= absorptivity of particle.

Heat Partition:

Power absorbed individually by Substrate = P_1
Power absorbed individually by Clad Powder Particles = P_2 +P_3

After incorporating individual energy absorption rate, heat transfer phenomena at the interface can be studied.

References:

[1] M. Picasso, C.F. Marsdan, J.D. Wangniere, A. Frenk, and M. Rappaz,"A simple but realistic model for laser cladding," Metallurgical and Materials Transactions: B, vol. 25, no. 2, pp. 281—291, 1994.

[2] Ehsan Toyserkani, Amir Khajepour, and Stephen Corbin, *Laser Cladding*, CRC Press, 2005.