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Mechanical and Electromagnetic Properties of Plasma Sprayed Ceramic Materials

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Abstract: Coatings of alumina and titania with different compositions were fabricated using plasma spraying method. The surface and cross-sectional morphological characterizations of Al_2O_3 and Al_2O_3/ TiO_2 powders and coatings were done using scanning electron microscope (SEM) and -ray Diffractometer (XRD. The microwave absorption of coated samples can be tailored by adding the TiO_2 for 8.2-12.4GHz (X-band) frequency range. The reflection loss of Al_2O_3 is -19dB at 10.495GHz whereas reflection loss of Al_2O_3/ TiO_2 87:13 is -23dB at 10.265GHz. The hybrid mixtures of both materials were used to increase the coating so as to increase the effective BW. The reflection loss result showed that coating of samples absorbed 90% of the incident electromagnetic radiation that was indicated by material's radar absorbing potential. This composition offered wide band absorption so it could be used to suppress radar signature.

Keywords: Plasma Spraying, Radar absorbing materials, , RADAR (Radio Detection and Ranging) Radar cross-section RCS stealth technology, X-ray Diffractometer XRD, Scanning Electron microscope SEM.

1. Introduction:

The microwave frequency range is from 0.3 to 300 GHz (approx 1mm to 100cm) [1]. The working of microwave signal is similar to optical signal which means that it can be refracted, reflected and diffracted as similar to visible line. To detect objects and their positions by transmitting short bursts of microwaves RADAR (Radio Detection and Ranging) has been developed. [2,8].

The major application of radar-absorbing materials and their composites are in military applications, so as to reduce radar visibility for different types of vehicles and are called as stealth technology. The microwave-absorbing coatings can be applied on the outer surfaces of military aircraft and vehicles helps to avoid detection by radar [6, 7, 14].

RAMs with less weight, thin, higher chemical stability, higher absorption frequency range and tremendous absorption performance are significantly preferred [9,10] Generally; the materials chosen are mixtures of different compositions which are then coated onto a substrate.

The re-radiated power density back at the radar is given by

$$P_r = \frac{P_t\ G}{4\pi R^2} \cdot \frac{\sigma}{4\pi R^2} \quad (1)$$

σ = RCS, G is maximum gain and P_t source radar power.
Maximum range of a RADAR beyond which target couldn't be detected is determined by its minimum strength S_{min}.

$$R_{max} = \left(\frac{P_t G s^2 t^2 \sigma}{S_{min}\ (4\pi)^2}\right)^{1/4} \quad (2)$$

Above equation clears that cross section is the parameter that affects the range and it should be reduced to enhance the survivability of a target. As per equation (2), if target would be dielectric, where back scatter can be reduced due to absorption [11-13].

Four RCS reduction techniques are shaping, active loading, passive loading and distributing loading. The distributive coating is a versatile and universal technique for RCS reduction as it could be applied at the stage of production of target without modification in design. Both alumina and titania have been used for fabricating RAMS.

The mechanical properties of coated samples were studied using XRD, SEM (Scanning Electron Microscopy) and their electric properties such as reflection loss by S parameter network analyzer.

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2. Investigational Work:-

2.1 Coating groundwork and categorization

The aluminum substrate was cut into small samples of size 20mm X 15mm X 4mm and the powder compositions used here were 30.18 µm sized Al_2O_3[99] (Praxair Surface Technologies) and 32µm sized Al_2O_3 TiO_2 [87:13] (Praxair Surface Technologies). The phase, morphological characterizations, particle size and particle size distribution were observed with help of XRD and SEM. In this paper Al_2O_3[99] taken as sample# [1] and Al_2O_3:TiO2 [87 : 13] sample# [2].
Both the powders were sprayed onto samples using Sulzer Metco M3 Plasma torch under atmospheric conditions at IPM Pvt.Ltd., Azadpur. The following parametric circumstances were kept the same for both the powders: current 600A, Voltage 70V ,gas flow rate 40lm^{-1},secondary gas 5.5lm^{-1}, powder feed rate 300gm^{-1}and spray distance is 100-110 mm. the substrates were grit blasted before spraying with surface roughness of 6-10Raµm as provided by IPM Pvt.Ltd., Azadpur. The XRD and SEM characteristics were performed at IIT, Delhi.
For cross-section the coated samples were cut with help of diamond saw and mounted using cold setting compound and cold resin. After cutting the coated samples were rubbed with sand papers and refined with a diamond paste at MEC, Jodhpur. Microstructure of polished coatings was observed using SEM at MEC, Jodhpur.

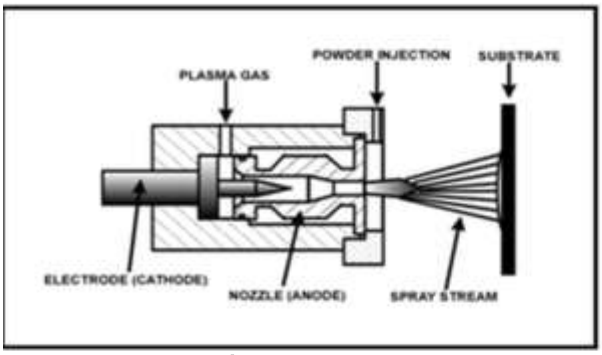

Fig 1 Plasma Spraying Process

3. Results and discussion

3.1. Mechanical Characterization

Fig 1[4] shows Plasma spraying process produces denser coatings, less porosity, better adhesion and allows the processing of any material [3-5,18]. In this process ,coating produced were porous and increasing the performance of target by keeping the composite microstructure remain unaltered as shown in fig 2 and 3 by SEM micrographs of powders and coated samples.

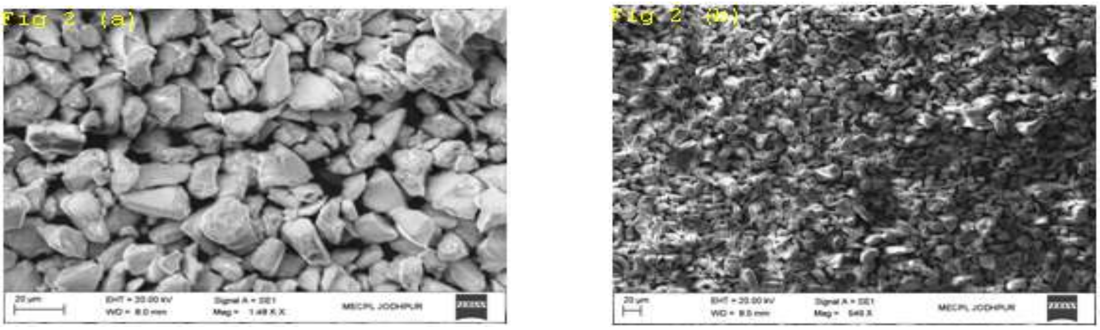

Fig 2(a) Morphology of powder samples (a) Al_2O_3[99] (b) Al_2O_3:TiO_2 [87:13]

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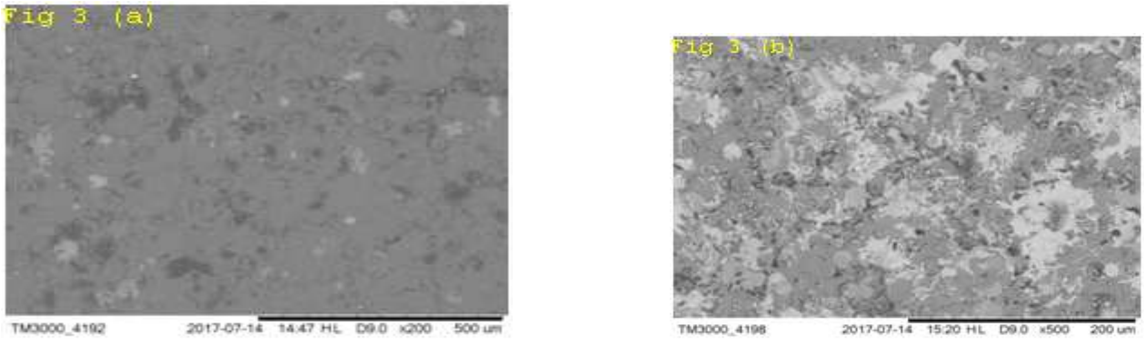

Fig 3 SEM micrographs of coated samples (a) Al_2O_3[99] (b) Al_2O_3:TiO_2 [87:13]

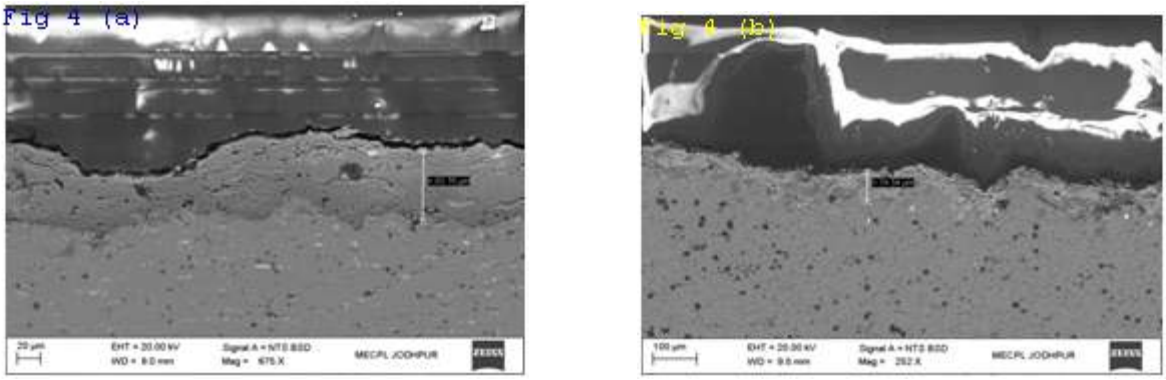

Fig 4 SEM cross-sectional micrograph of coated samples (a) Al_2O_3[99] (b) Al_2O_3:TiO_2 [87:13]

The cross-sectional SEM micrographs of Al_2O_3[99] and Al_2O_3:TiO_2 [87:13] were indicated in fig 4 that verified the presence of TiO_2 (13%) in Al_2O_3. The content of Al_2O_3[99] and Al_2O_3:TiO_2[87:13] powders were quantitatively evaluated from XRD plot which was performed at IIT, Delhi. A new phase Al_2TiO_5 occurred due to the reaction between Al_2O_3 and TiO_2 powders as shown in figure 5.

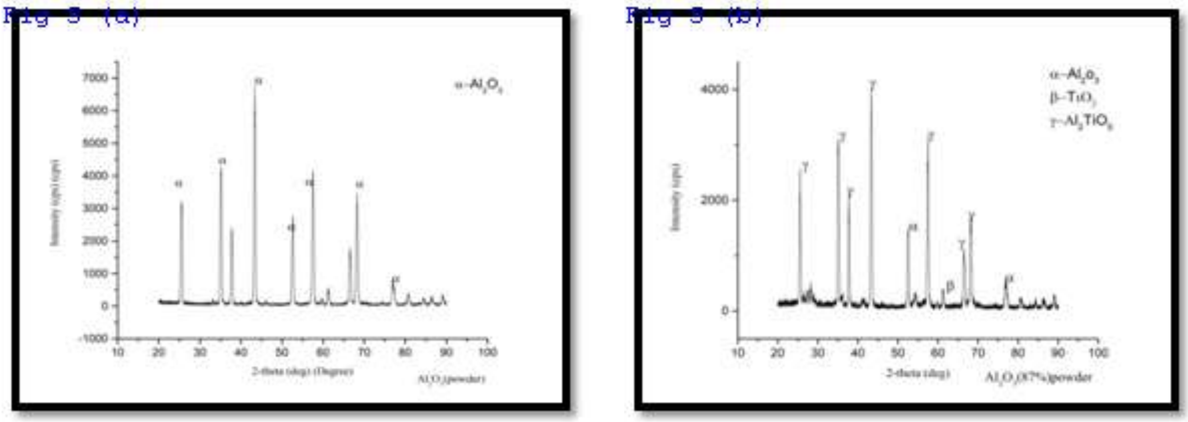

Fig.5 (a) XRD images of powder samples (a) Al_2O_3[99] (b) Al_2O_3:TiO_2 [87:13]

3.2 Electrical Characterization

The reflection loss is ratio of the incident power to the reflected power. [15] For a single layer RAM The incorporation of electromagnetic energy of a as a purpose of frequency can be considered systematically using Equations 3 and 4 (Balanis, 1989; Chen et al., 2004) [4].The reflectivity of coating is expressed as

$$R = 20log(\tau) = 20log\left|\frac{z_i - z_0}{z_i + z_0}\right| \quad (3)$$

τ = Reflection Coefficient, Z_i input impedance and Z_0 Intrinsic Impedance of free space 377Ω.
As per transmission theory the input impedance of absorber Z_i [16-17]

$$Z_i = \eta tanh(\gamma d) \quad (4)$$

Where, $\eta = Z_0\sqrt{\mu/\varepsilon}$

and $\gamma = j\frac{2\pi f}{c}\sqrt{\mu\varepsilon}$

η, γ, d *and* μ indicate the intrinsic impedance, propagation constant, thickness, relative complex permittivity and permeability of the composite coating respectively (Balanis, 1989; Chen et al., 2004). The velocity of light is represented by c and frequency as f of incident wave.

For the design of microwave absorbing coated samples the two conditions should be considered are.

1) Impedance matching: It means that input impedance of the coated samples should be close to free space impedance for the maximum microwave absorption.

2) The wave incident upon the material layer should be attenuated rapidly. [19-22].

The reflection loss s_{11} of coated samples was measured with HP87576 Network Analyzer and waveguide WR-90 as shown in fig 6 for frequency range from 8 to 12 GHz (X-band) at Vidyut Yantra Udyog ,Modi Nagar.

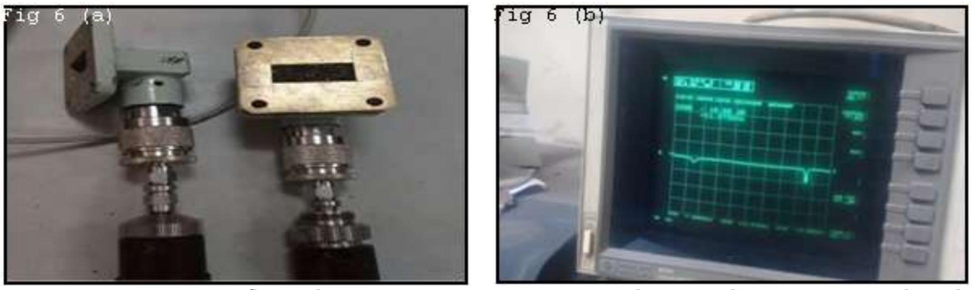

Fig 6 Reflection loss measurement setup (a) Waveguide WR-90 (b) HP87576 Network Analyzer

The various measurement techniques used for microwave frequency were free space measurement technique, resonant cavity technique, transmission line technique and dielectric probe technique.To measure S_{11} parameter (reflection loss) dielectric probe has been used. Before measurement calibration of Network analyzer has been done.

a) Calibration Phase

The network analyzer must be calibrated before any S-parameter measurements are performed. The system must be allowed to warm up for at least 1 hour before calibration, and the calibration standards must be at ambient room temperature. It is convenient to switch on the analyzer and expose the calibration devices to air before measurements are made.

b) Calculation Phase

After calibration, coated samples were placed under surface of WR-90 in such a manner so that it covers WR-90. The measurement was done for the X- band range with WR-90. The reflection loss or S_{11} parameter at various points in the X-band range from network analyzer was plotted using MATLAB.

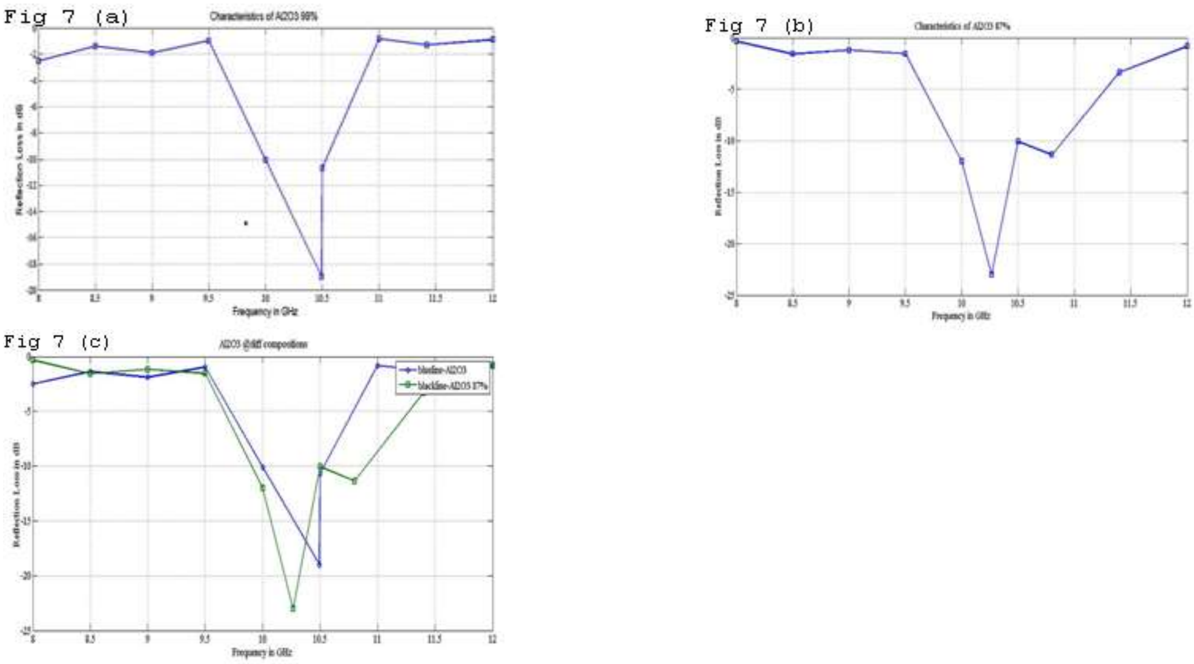

Fig 7 Reflection loss S_{11} of (a) Al_2O_3 [99] (b) Al_2O_3:TiO_2 [87:13] (c) combined plot of both the samples

The reflection loss was observed for both coated samples i.e. sample#1 and sample#2 for X-band freq range. For RL≤ 10 dB results 90% microwave absorption and it was observed that sample#1 showed good absorption properties from 10.495 to 10.55 GHz and maximum reflection loss of -19dB at 10.495GHz with a bandwidth of 0.055GHz , whereas with addition of TiO_2 means sample#2 with reflection loss of -23 dB at 10.265GHz absorption and bandwidth of 0.8GHz was monitored from 10.0 to 10.8GHz as shown in fig 7(b).
Hence it was being concluded that sample#2 with composition of Al_2O_3:TiO_2 [87:13] ceramics provide better absorption and enhanced bandwidth than sample#1 Al_2O_3 [99] as shown by S_{11} characteristics of both the samples plotted simultaneously as shown in fig7(c).

4. Conclusion

Al_2O_3 / TiO_2 coatings with different compositions was fabricated using plasma spraying and experimentally characterized using network analyzer for X-band. High temperature plasma flame caused phase transformation as indicated by XRD plot. It was observed that plasma spraying produced effective RADAR absorbing coatings for sample#2 (Al_2O_3 :TiO_2, 87:13) with better reflection loss of -23 dB for the frequency range of 10.0-10.8 GHz than as the maximum reflection loss for sample#1 (Al_2O_3 99%) was -19 dB from 10.495 -10.55GHz. With addition of TIO_2 microwave absorbing properties had been improved with better bandwidth**.**

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