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Enhanced Reflection Loss Performance of Square Based Pyramidal Microwave Absorber Using Rice Husk-Coal

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Abstract—Rice husk and coal is an innovation in enhancing the microwave absorption properties of pyramidal microwave absorbers to be used in radio frequency anechoic chambers. An anechoic chamber consists of radar absorbing material (RAM) along its wall; floor and ceiling to eliminate unwanted reflections to create electromagnetically quite environment. To design the pyramidal microwave absorber, coal has been added to rice husk. This innovative material combination has been investigated to determine the best reflectivity performance of pyramidal microwave absorbers. In the commercial market, polyurethane and polystyrene are the most popular foam based material that has been used in pyramidal microwave absorber fabrication. Simulation tool that has been used is CST Microwave Studio. Simulation based comparison of rice husk and combination of rice husk plus coal is done in the frequency range of 0–20 GHz. Chemicals used to intact the powdered form of rice husk and coal are polyester resin, methyl ethyl ketone peroxide (MEKP) and cobalt. Pyramidal microwave absorber has been tested using dielectric probe method and radar cross section method (RCS). Reflection loss performance is tested in the frequency range of 8.2 to 12.4 GHz.

1. INTRODUCTION

Agricultural waste is the waste produced on farm through various farming activities. Residues of crops are materials like leaves, seed pods, stalks and stems left in agricultural fields after the crop has been harvested. Agricultural waste like rice husk, rice straw, sugarcane bagasse, banana leaves, etc. can be used as an alternative for microwave absorber used in the anechoic chamber [1]. Rice husks are the natural sheaths that form on rice grains during their growth and removed as waste during the processing of rice in mills. Every year approximately 120 million tonnes of paddy are produced in India. This gives around 24 million tonnes of rice husk and 4.4 million tonnes of rice husk ash every year [2]. Rice husk is unusually high in ash, which is 92 to 95% silica, highly porous and lightweight, and is traditionally burnt in the field or dumped [3]. Table 1 shows the chemical composition of rice husk [4].

The presence of 35.77% of carbon that occurs naturally in rice husk is responsible for good reflection loss performance for the microwave absorbers. Mixture of rice husk and powdered coal is used as the pyramidal microwave absorber [5]. Figure 1 shows various steps to the development of rice husk-coal pyramidal microwave absorber. Figure 2(a) shows collected rice husk from paddy fields, (b) shows grinded rice husk, (c) shows the mixture of grinded rice husk and coal.

The organic component of coal consists of chemical compounds from carbon, hydrogen, oxygen, sulphur, and nitrogen [6]. Due to 75% of carbon in it, coal is used to enhance microwave properties of rice husk. Table 2 shows weight percentages of chemical compounds present in it naturally.

In order to define physical and chemical properties related to various materials, we need to measure the dielectric properties of the material. By definition, dielectric properties are a measure of the

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Table 1. Chemical composition of rice husk [4].

Element	% Element
Silicon Dioxide	22.24
Carbon	35.77
Hydrogen	5.06
Oxygen	36.59
Nitrogen	0.32
Sulphur	0.02

Table 2. Weight percentages of chemical compounds present in coal [6].

Chemicals Compounds	Weight Percentage (%)
Ash	10
Oxygen	8
Hydrogen	5
Nitrogen	1.5
Sulphur	0.5
Carbon	75

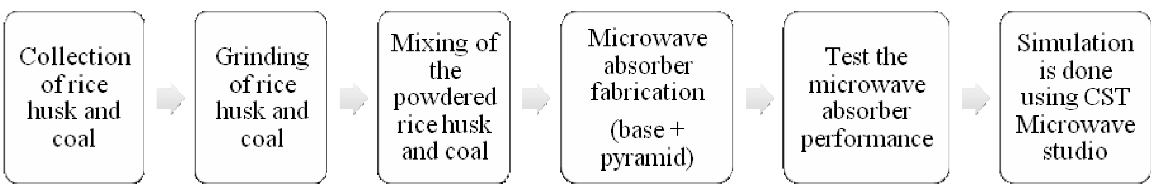


Figure 1. Development of rice husk-coal pyramidal microwave absorber.

(a) (b) (c)

Figure 2. (a) Rice husk collected from paddy. (b) Grinded rice husk. (c) Mixture of rice husk and coal.

polarizability of a material when subjected to electric field [7]. Parameters to measure are dielectric constant, loss tangent and reflection loss. The permittivity of a material has both real and imaginary representation. The real part of permittivity, ε_r' is a measure of how much energy from an external electric field is stored in a material. The imaginary part of permittivity, ε_r'' is called the loss factor and is a measure of how dissipative or loss of a material is to an external field. The dissipation factor or loss tangent, $\tan\delta$ is a parameter of a dielectric material that quantifies its inherent dissipation of a electromagnetic energy [8, 9]. The formula of loss tangent is shown below:

$$\tan\delta = \varepsilon_r''/\varepsilon_r'$$

The reflection loss or reflectivity, R can be expressed as the absorbing performance of the material and is given as:

$$R = 10\log_{10}(P_r/P_i)$$

where P_r is the plane wave reflected power density and P_i the plane incident power density.

2. MICROWAVE ABSORBER FABRICATION

Mostly pyramidal shaped absorbers are used in development of anechoic chambers because they have least amount of open surface area, hence provide maximum microwave absorption [10]. The pyramidal microwave absorber is formed in two parts. The first part is the base part (square based) of 15 cm∗15 cm with the thickness of 2 cm. Second part is the pyramidal shape having square base of 5 cm ∗ 5 cm and height of 13 cm. The pyramidal microwave absorber contains 9 tips per piece. To give shape to the mixed material, moulds are prepared in the sheet metal workshop using aluminium sheet. Figure 4(a) shows the moulds of pyramidal shape. Ratio in which the rice and coal are mixed is 60 : 40. For comparison of the reflection performance of rice husk and the mixture of rice husk and coal, a sample of only rice husk is prepared of the WR 90 waveguide size and is tested using dielectric probe method for its dielectric properties like dielectric constant and tangent loss.

In order to give shape to the absorber, some hardening as well as binding agent is required. As per earlier observations [11], polyester resin is used as binding agent. In this work, cobalt has been used as an accelerator in order to increase the rate of reaction. MEKP is the catalyst added to polyester resins. As the catalyst mixes with the resin, a chemical reaction occurs; creating heat which cures the resin. Cobalt here reduces the gel time and hence enhances the speed of reaction and help in the formation of solid moulds in less time [12, 13]. Figure 3 shows the mixing process to make the rice husks pyramidal microwave absorbers. Preparation of mixture including all the chemicals used is done in a proper composition. For a single pyramid, 45 gms of rice, 30 grams of coal, and 55 grams of polyester resin is added to bind the material together, 0.55 grams of cobalt is added to accelerate the rate of reaction and 1.1 grams of MEKP is added as a catalyst to the reaction.

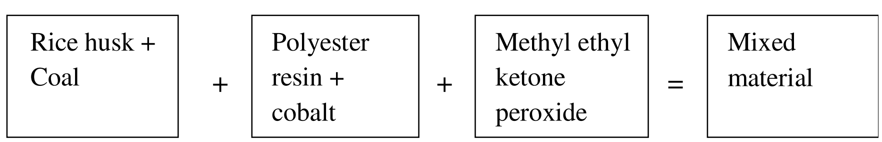


Figure 3. The mixing process to make the rice husks pyramidal microwave absorbers.

After preparing the mixture using the composition mentioned above, the mixture is added layer by layer into the moulds and is kept untouched for an hour. The pyramidal shaped absorbers are arranged in a 3×3 array over the 2 cm thick base. Figure 4(a) shows the pyramidal moulds prepared, (b) and (c) show the final mixture prepared and the mixture settled in the moulds respectively. Figure 5 shows 3×3 pyramidal structure with a 2 cm thick base.

3. TESTING METHODS

Various measurement techniques are available at microwave frequencies. These include a 50 GHz Agilent network analyzer having Agilent Technologies 85071 measurement software to define the dielectric properties. In this research work, the method used for the calculation of dielectric constant is dielectric probe method. RCS method is used to measure reflection loss performance of microwave absorber.

(a) (b) (c)

Figure 4. (a) Pyramidal moulds. (b) Final mixture. (c) Mixture in the moulds.

Figure 5. 3×3 array of microwave pyramidal structure.

3.1. Dielectric Probe Method

In this method, two co-axial cables are used to calculate the dielectric constant of material under test in the range of 8 to 12 GHz. The sample has to be in the shape that fits exactly inside the WR 90 waveguide. The empty WR 90 Waveguide is inserted between the two port co-axial cables of VNA and then the dielectric constant of air is made to real at value 1. The dielectric probe method is applied for both the samples of rice husk and mixture of rice husk and coal. Figure 6(a) shows WR 90 waveguide and coaxial cables (b) shows Material under test.

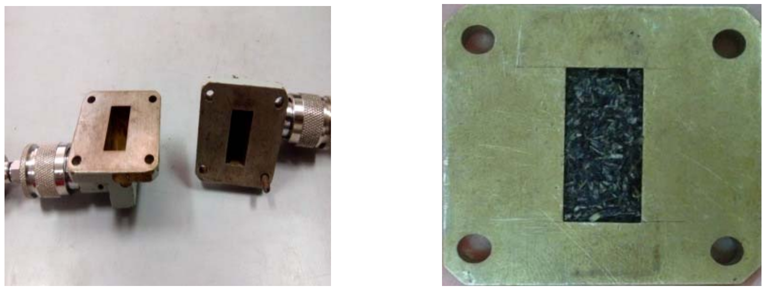
After the calibration is done, the material under test is placed inside the WR 90 Waveguide and then it is placed between two ports. Then the calculation for the dielectric constant of the material is performed by the VNA and results are shown along with WR 90 waveguide filled with material under test. Table 3 shows the different values of dielectric constant and tangent loss of rice husk and the mixture of rice husk and coal.

Table 3. Dielectric constant and tangent loss values of rice husk and the mixture of rice husk and coal.

Sample	Dielectric Constant	Tangent Loss
Rice Husk	1.913503	0.079273
Mixture of rice husk and coal	2.504677	0.08598

3.2. Radar Cross Section Measurement Method

Radar cross section is defined as the area that can be perfectly reflected back when an electromagnetic wave is transmitted from source to target position [14]. The frequency range chosen for the measurement



(a) (b)

Figure 6. (a) WR 90 waveguide and coaxial cables. (b) Material under test.

(a) (b)

Figure 7. (a) Set up for the testing of 3×3 pyramidal structure using RCS method. (b) Software set up shown on 50 GHz VNA.

is chosen to correspond to the radar frequency band (8.2 to 12.4 GHz for WR-90 X band Waveguide). X band horn antenna is attached to the probe which is connected to VNA. Firstly, aluminium sheet is kept under the horn antenna to calibrate VNA and then 3×3 arrays of rice husk plus coal is kept over the aluminium sheet under the horn antenna placed at 90 degree above the array as shown in the figure below. Graph of reflection loss v/s frequency is obtained on the screen of VNA. Figure 7(a) shows set up for the testing of 3×3 pyramidal structure using radar cross section method, (b) shows the software setup on VNA.

4. RESULTS AND DISCUSSIONS

Reflection loss results are obtained from RCS Measurement Method. VNA gives a plot for S_{11} against frequency which gives the reflection loss. Result from the RCS measurement shows a good reflection loss performance as it gives an average value better than -10 dB. Figure 8 shows the tested results of reflection loss performance for 3×3 array in the frequency range of 8.2 to 12.4 GHz as shown by VNA.

At four different points of frequencies, reflection loss greater than -40 dB is obtained. This result is equivalent to the conventional foam absorber which shows reflection loss lesser than -50 dB. The average reflection loss of tested sample of rice husk plus coal is around -44 dB in the frequency range of 8–12 GHz with maximum reflection loss at -52 dB at 11 GHz.

The reflection loss performance of microwave absorbers in the frequency range of 0 to 20 GHz is obtained through CST Microwave Studio. Vector Network Analyser generates a file which comprises of value of dielectric constant at different frequencies in the range of 8.2 to 12.4 GHz. This file is loaded in the CST Microwave studio [15] and then exact reflection constant is calculated by it and is shown as a graph between reflection loss and frequency. Simulation set up is shown in the Figure 9.

A port is applied above the 3×3 pyramidal array structure which acts as a source of electromagnetic waves. Through this port, EM waves are applied on the pyramidal array structure and hence absorption is calculated in terms of s parameters. For comparison between two different microwave absorbers, rice

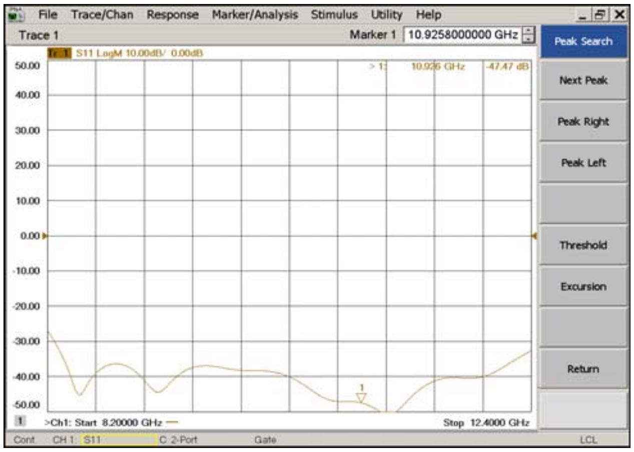


Figure 8. Reflection loss performance for 3×3 array in the frequency range of 8.2 to 12.4 GHz as shown by VNA.

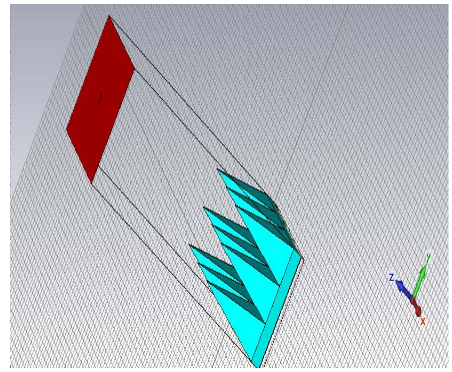


Figure 9. Simulation of array in CST Microwave Studio.

Table 4. Reflection loss values of rice husk in 0 to 20 GHz.

S. No	Frequency (GHz)	Reflection Loss (dB)
1	0	−11.0
2	8	−31
3	8.3	−33
4	9.1	−34
5	10	−34
6	12	−36
7	12.8	−35
8	13.8	−38
9	14	−33
10	15	−35
11	16	−32
12	16.7	−33
13	17.3	−33
14	20	−29

husk and mixture of rice husk and coal, simulation is performed to get two different plots by giving the values of dielectric constant and tangent loss to CST Microwave studio in the frequency range of 0 to 20 GHz. The simulated results of S_{11} plot obtained for rice husk is shown in Figure 10. Different Reflection loss values are considered at fourteen frequencies from 0 to 20 GHz for rice husk as shown in Table 4.

The average reflection loss of rice husk is −31.928 dB from 0–20 GHz. The maximum reflection loss obtained in the plot is −38 dB at 13.8 GHz. Similarly, a plot is obtained for the mixture of rice husk and coal as shown in Figure 11. Different reflection loss values are considered at fourteen frequencies from 0 to 20 GHz for rice husk and coal as shown in Table 5.

Average reflection loss of tested sample of rice husk and coal is −43.5 dB. The maximum reflection loss obtained in the graph is −62 dB at 7.9 GHz. The reflection loss of rice husk is enhanced by −11.5714 dB by adding coal which makes a huge difference in terms of its microwave absorption capacity. The reflection loss performance of rice husk and coal has become better comparatively in the low frequency ranges.

Table 5. Reflection loss values of 'rice husk and coal' in 0 to 20 GHz.

S. No	Frequency (GHz)	Reflection Loss (dB)
1	0	−55
2	4	−22
3	6	−31
4	7.2	−49
5	7.9	−62
6	8.4	−51
7	10	−43
8	10.8	−47
9	11.8	−47
10	13.2	−33
11	15	−75
12	16.5	−35
13	18	−30
14	20	−29

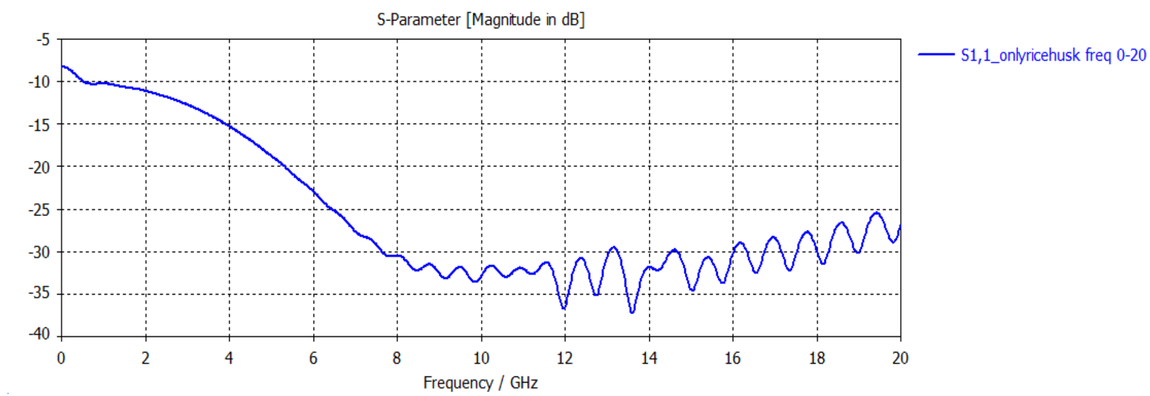


Figure 10. Reflection loss performance of rice husk in 0 to 20 GHz.

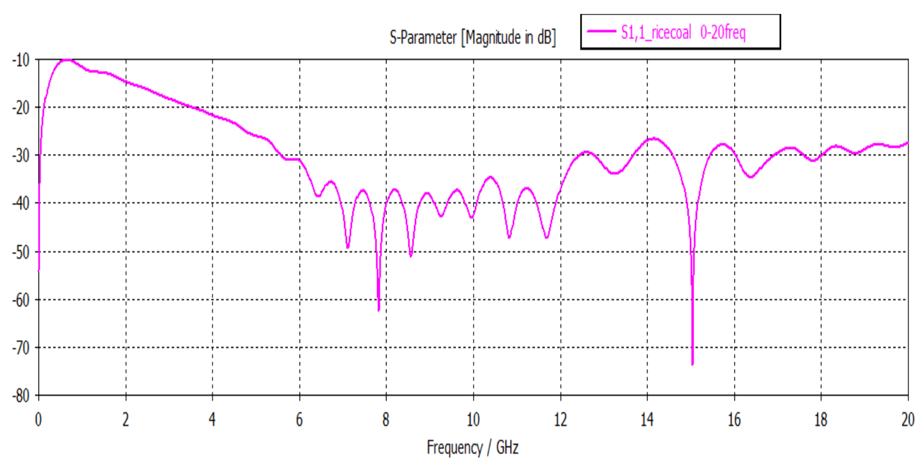


Figure 11. Reflection loss performance of 'rice husk and coal' in 0 to 20 GHz.

5. CONCLUSION

From the reflection loss performance of the mixture of rice husk and coal, it is concluded that coal has the potential to be used as an alternative material in designing the pyramidal microwave absorber. There is a window seen in rice husk plus coal sample from 6–12 GHz where they perform the best giving an average reflection loss of -45 dB. Moreover, using recycled material such as rice husk, landfill waste can be reduced. Also, it can significantly reduce the cost of production of the microwave absorber as compared to using the expensive material like polyurethane and polystyrene. In future, by adding carbon rich materials like iron fillings and graphite, absorption can be further enhanced. Composition of resin, hardener and accelerator can be changed for studying its effect on absorption. Catalysts like Mn, Ni, Fe etc. can be used to see its effect on rate of reaction and reflection properties.

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