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THE PERFORMANCES OF SINGLE AND DOUBLE-LAYER MAGNETIC SLAB ABSORBERS PREPARED FROM *Mount Bromo* SAND, EAST JAVA, INDONESIA AS MICROWAVE ABSORPTION MATERIALS

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ABSTRACT

Slab absorbers are a significant subject of interest not only for commercial purposes but also for military uses. Compact absorbers made from one or two slab layers are unable to achieve the necessary wave absorption across a broad frequency range, aside from a few absorption peaks. Therefore, developing a new type of absorber to fulfill the requirement for broad wave band absorption is essential. This study examined how well single and double-layer microwave absorbers made from *Mount Bromo* sand in East Java Indonesia absorb microwaves in the X-band frequency range. A magnetic slab absorber (MSA) has been designed by incorporating a polymer medium into the absorbing matrix. The optimum RL values below –5 dB (>70% absorption) had been resulted by single layer compact slab absorbers in the x-band frequency range with a thickness of 0.5 cm for reflection angle of 25 degrees. Reflection loss tests demonstrate that the MSA showed outstanding absorption performance in the frequency range of 7 to 13 GHz.

Keywords: Magnetic Slab Absorber, Mount Sand, Microwave Absorption, Reflection Loss, X-Band Frequency.
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INTRODUCTION

Since the Gulf War, microwave absorption materials have been a significant area of interest for military applications and are gaining increasing attention in radar detection, communication, and instrumentation fields. Many countries are very interested in radar-absorbing material (RAM), particularly for industrial radar systems. With the rising demand for increasing use of electronic equipment and digital devices of wave materials, some general features of strong absorption of electromagnetic waves, perfect reflection loss, broadening the absorption bandwidth, low thickness, lightweight and small bulk are more important.[1-6] As a result, slab microwave absorption materials have become increasingly urgent and are being studied by a growing number of researchers. Current slab microwave absorbers, typically made by combining a wave-absorbent material with a bulk material, have limited absorption bandwidth.[7-10] Researchers have explored several ways to improve their performance, including optimizing the absorbents used[8-11], combining different absorbents[12-13], and using multi-layered structures.[14] Researchers have explored various slab absorber designs. For instance, Pattanayak *et al.* simulated single and multi-layer absorbers.[14] Choi *et al.* created a double-layer epoxy resin/multi-walled carbon nanotube (MWCNT) absorber that achieved 90% absorption across the entire X-band (8.2–12.4 GHz).[15] Choi *et al.*[16] also investigated silicon carbide/epoxy composite slabs and reported a minimum reflection loss of 31.0 dB with a 3.4 GHz bandwidth at -10 dB. As highlighted in previous work, multi-layered absorbers offer improved absorption over a wide frequency range, but they are complex and expensive to produce. This study introduces a simpler, single-layer and double-layer magnetic slab absorber (MSA) made from magnetic and non-magnetic particles of the Mount Bromo sand in an epoxy resin. To the best of our knowledge, this design which has not been previously reported, offers a less complex fabrication process.

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EXPERIMENTAL

Materials and Methods

The primary material, sand from Mount Bromo, East Java, Indonesia, was used in this study. To obtain magnetic powder, Mount Bromo sand was first separated using a permanent magnet and subsequently milled for 15 min using a planetary ball mill. Then, the magnetic and nonmagnetic powders were obtained. Simultaneously, the epoxy resin was prepared in air. The magnetic and non-magnetic powders were then separately mixed with epoxy resin using a motor mixer, maintaining a 70% mass fraction of the powder in each mixture. These mixtures were cast to create the compact slab absorber samples.

General Procedure

Figure-1 illustrates the experimental setup of the vector network analyzer and standard horn antennas. Compact slabs (30 x 30 x 0.5 cm) were created by cold-compressing the magnetic and non-magnetic powder-epoxy mixtures at 1 MPa and room temperature (Fig.-2). Using a Rohde Schwarz ZVA 67 vector network analyzer (VNA) and standard horn antennas in a mini anechoic chamber, the reflection loss of both single and double-layer absorbers was measured across the 7 to 13 GHz frequency range. A permagraph (capable of up to 1 tesla) and an optical microscope were used to analyze the samples' magnetic hysteresis loops and surface morphology, respectively.

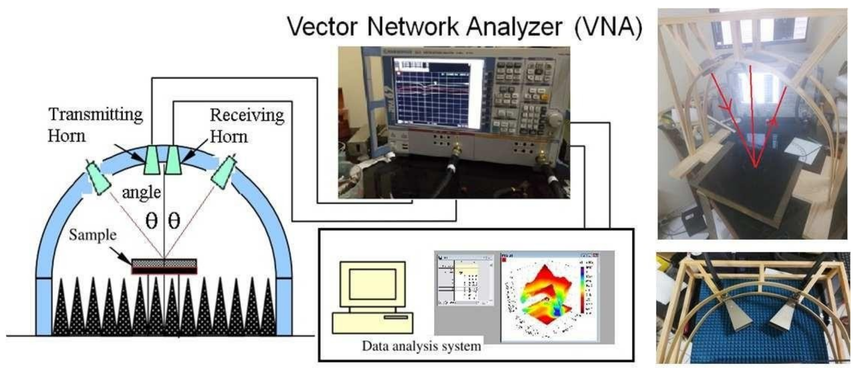

Fig.-1: The Experimental Scheme Vector Network Analyzer and Standard Horn Antennas in the Frequency of 7–13 GHz in the Mini Anechoic Chamber

Detection Method

The slab samples were further characterized using a Permagraph (Magnet-Physik, 2T) up to 1 tesla applied magnetic field at room temperature to determine their magnetic hysteresis loops, and an optical microscope to examine their surface morphology.

RESULTS AND DISCUSSION

Figure-2 shows the magnetic and nonmagnetic slab composites with different particle sizes as a filler and epoxy resin binder as a matrix. From the surface morphology images, it could be seen that the particles have a wide particle size distribution after ball-milling and the magnetic separation process.[17]

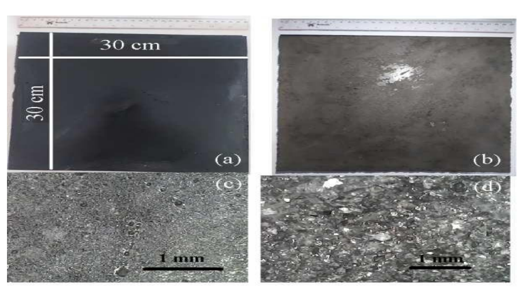

Fig.-2: (a) The Magnetic and (b) Nonmagnetic Rectangular Slabs with a Size of 30 x 30 x 0.5 cm with the Surface Morphology Images

The magnetic particle size is smaller than the nonmagnetic particle size. With 70% in mass fraction of the powder content in the epoxy resin matrix, the slab composites represent flexible microwave absorbers having potential applications in electronic and communication devices. To note, the intrinsic properties of the material consist of the magnetic field and electric field possessed by the material.[18,19] While the influence of extrinsic properties, among others, is related to the shape and thickness of the material. Along with the times, the development of thinner and lighter electromagnetic wave absorbing materials with wider bandwidth continues to increase. The absorption properties of a material will also be better if the particle size is smaller.[20] Generally, the crystal size increases with increasing sintering temperature due to the diffusion process between the nearest neighboring particles as well as the core reaction between the constituent atoms.[21]

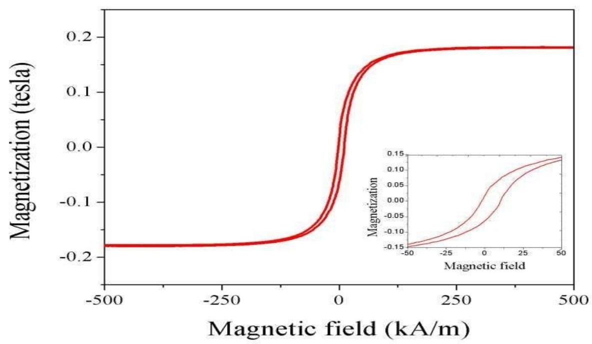

Fig.-3: Magnetic Hysteresis Loop of Slab Absorber at Room Temperature

Figure-3 shows the room-temperature magnetic hysteresis loop of the magnetic powder used in the slab absorber. The hysteresis loop shows that the magnetic powders of the slab absorber have representative ferromagnetic behavior. Then, the coercivity (Hc) and saturation magnetization (Ms) values of the magnetic powders of the slab absorber are 10.72 kA/m and 0.175 tesla, respectively. The magnetic properties show magnetite Fe_3O_4 as main phases of the magnetic powder. As shown, the magnetic curve has a slender curve shape. This indicates that the material is soft magnetic because it has a small H_c value. The H_c value is influenced by the size of the crystal. The H_c value increases with increasing crystal size. At small crystal sizes, there is a decrease in anisotropy energy.[22] From the experimental setup, which used a VNA and standard horn antennas (for both transmission and reception), the operating process was between 7 and 13 GHz. Single slab absorbers (30 x 30 x 0.5 cm) were initially placed flat to fully cover the waveguide's contact area. The VNA then measured the material's transmission and reflection properties at various reflection angles, ranging from 5 to 45 degrees. The working principle of VNA is by assessing the reflection, transmission, and absorption of a material. When the wave hits the metal material, the wave will be reflected; when it hits the transparent material, the wave will be transmitted; and when it hits the absorbing material, the wave will be absorbed.[23]

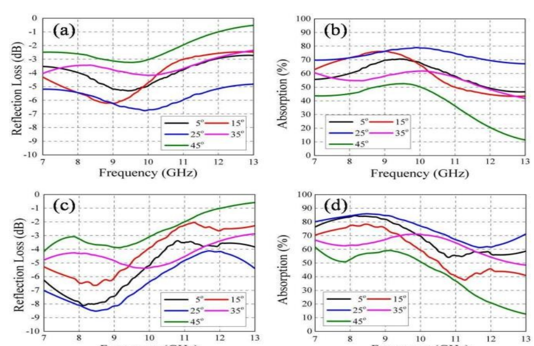

Fig.-4: The Reflection Loss (RL) and Absorption (A) of the Magnetic (a,b) and Nonmagnetic (c,d) Single Slab Absorbers with a Thickness of 0.5 Cm in the Frequency Range of 7–13 GHz.

Figure-4 presents the reflection loss (RL) and absorption (A) values of the receiving parameters (*r*) for the single slab absorbers, measured across a frequency range of 7 to 13 GHz. This reflection loss value will show the absorption ability of the material.[24] To analyze the microwave absorption abilities, reflection loss (RL) and absorption (%) values for the samples were calculated using the equations RL (dB) = 20 Log |r| and A (%) = 100(1 – $10^{RL/10}$), respectively. It was obtained that the magnetic and nonmagnetic single slab absorbers exhibited an optimum RL with a reflection loss of less than −5 dB (70% absorption) for reflection angle of 25 degrees. Compared with single slab absorbers for reflection angle of 25 degrees, double slab absorbers exhibited a higher RL and absorption (A) in the frequency range of 7–13 GHz.As shown in Figure 5a, the lowest RL is –16.77 dB at 12.26 GHz for reflection angle of 25 degrees and RL below –10 dB (>90% absorption) are 10.81–13.00 GHz for the magnetic + nonmagnetic double slab absorber. While for nonmagnetic + magnetic double slab absorber (Figure 5c), the minimum RL is –36.79 dB at 11.13 GHz and RL below – 10 dB (>90% absorption) are 10.19–12.09 GHz for reflection angle of 5 degrees.

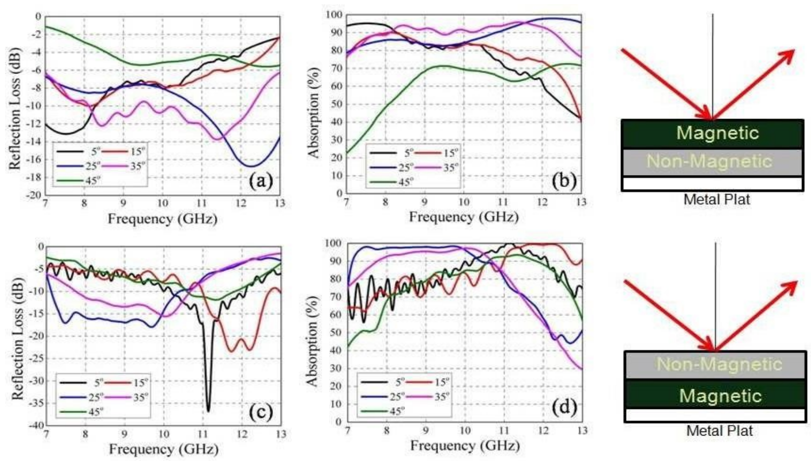

Fig.-5: The Reflection Loss (RL) and Absorption (A) of the Magnetic + Nonmagnetic (a,b) and Nonmagnetic + Magnetic (c,d) Double Slab Absorbers with a Thickness of 1.0 cm in the Frequency Range of 7–13 GHz.

It proved that the double-layer magnetic slab absorbers (MSA) result in prominent microwave absorption. The resulting reflection loss (RL) value shows that the absorber material is able to absorb waves at the measured frequency. As a reference, the RL results obtained will show the percentage value of absorption, if the RL value of 10 dB means that wave absorption can reach 90%, and if the RL value of 20 dB means wave absorption reaches 99%.[25] Furthermore, the reflection angle is a significant variable for the definition of the microwave absorption abilities of magnetic slab absorbers (MSA). For the description of the effect of reflection angle, the RL and 3D image map of the double layer magnetic slab absorbers (MSA) with thicknesses of 1.0 cm are shown in Fig.-6.

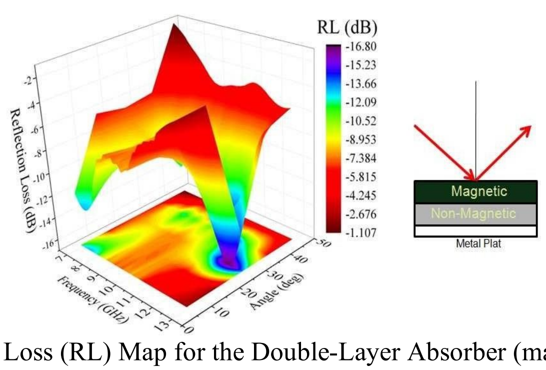

Fig.-6: The 3D Reflection Loss (RL) Map for the Double-Layer Absorber (magnetic and non-magnetic)

Figure-6 shows a 3D graph for the map of RL values as a function of frequency and angle for the double-layer plate. It can be seen in the figure that the optimum absorption occurs in the frequency range of 10-

13 GHz with an angle in the range of 20-40 degrees which results in an RL smaller than -10 dB (90% absorption).

CONCLUSION

Single- and double-layer compact slab absorbers were successfully synthesized by the casting method and cool- cool-compressing method. The optimum RL values below 5 dB (>70% absorption) had been resulted by single-layer compact slab absorbers in the x-band frequency range with a thickness of 0.5 cm for a reflection angle of 25 degrees. The lowest RL values below –10 dB (>90% absorption) had been obtained for reflection angles of 5 and 25 degrees of the nonmagnetic+magnetic and magnetic+nonmagnetic double slab absorber, respectively. The demonstrated reflection loss and absorption capabilities suggest that the MSA shows promise for effective microwave absorption in the 7–13 GHz range.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

The present work is related to *SDG-7: Affordable and Clean Energy*. All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

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