GEOMETRIC INFLUENCE OF 3D-PRINTED MULTILAYER STRUCTURES FOR RADAR STEALTH APPLICATIONS

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Abstract

This study investigates the geometric influence of 3D-printed multilayer structures composed of polylactic acid (PLA), conductive PLA, and thermoplastic polyurethane (TPU) for radar stealth applications. The designed multilayer architectures incorporate triangular and honeycomb geometries aimed at enhancing electromagnetic wave attenuation. By strategically engineering the layer configurations, the structures facilitate multiple internal reflections and improve impedance matching, thereby optimizing radar wave absorption and contributing to the development of lightweight, customizable stealth materials.

Introduction

Microwave-absorbing materials have gained significant attention in the development of stealth technologies due to their great potential to reduce or prevent the detection of combat platforms — such as missiles, submarines, aircraft, and vehicles — by enemy radar systems. Traditionally, these coatings employ polymers capable of attenuating the reflected electromagnetic (EM) wave signals through interactions between the incident wave components and the electric and/or magnetic dipoles of the material. This interaction leads to a decrease in the intensity of the reflected signal, attributed to the material's electrical permittivity and magnetic permeability. Recently, the introduction of geometrically engineered multilayer structures has emerged as a promising strategy to enhance these effects. The geometric configuration plays a crucial role in wave absorption by promoting mechanisms such as multiple internal reflections and thickness resonances, which further improve EM wave attenuation. Therefore, the combination of advanced polymer formulations with optimized geometric architectures represents an innovative approach to improving the performance of stealth materials.

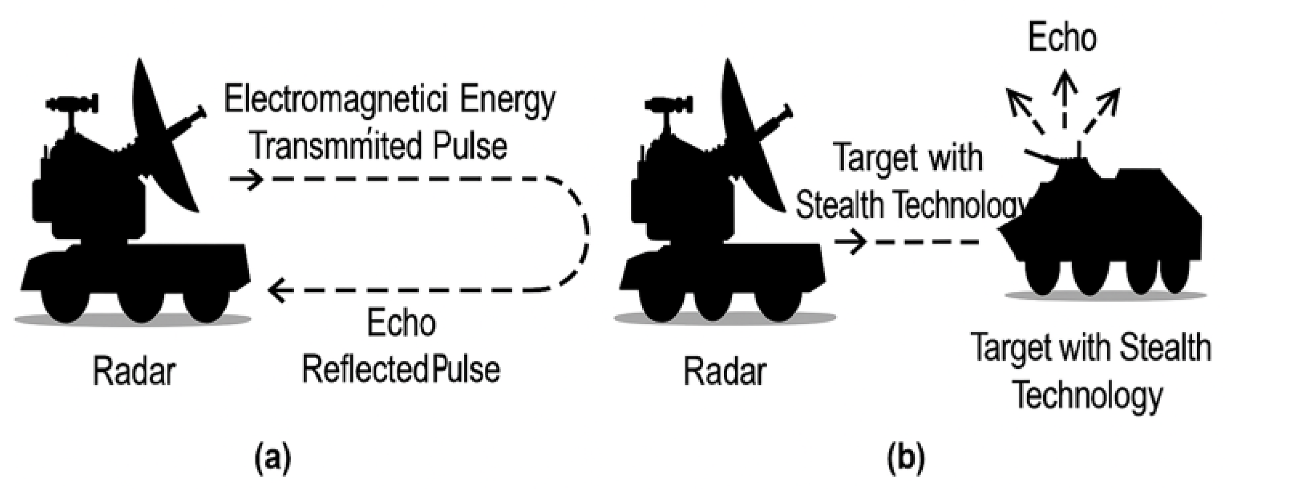

Figure 1 - (a) Target without absorber material and (b) Target with geometric absorber material

Materials

Parameters	Values
Nozzle diameter	0.4mm
Layer thickness	0.2mm
Nozzle temperature	215 °C
Bed temperature	70 °C
Infill density	100%

Table 1 - 3D printing parameters.

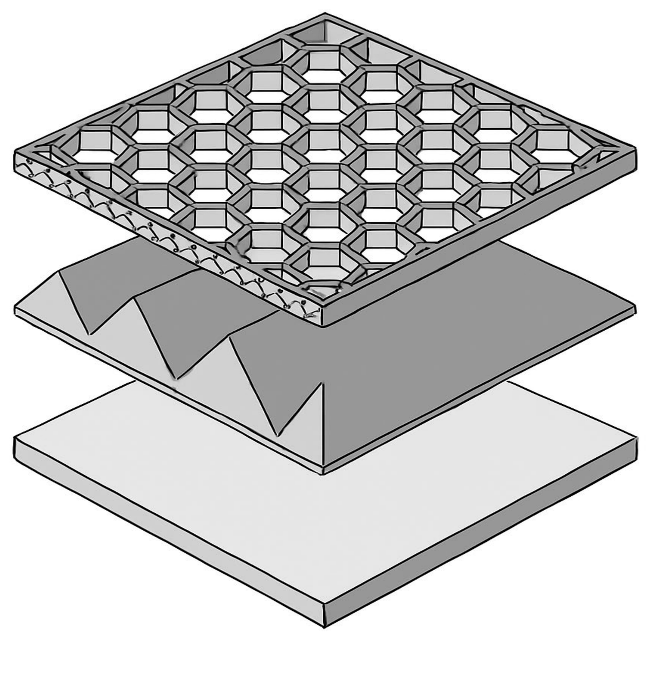

Figure 2 - Illustration of the printed sample

Figure 3 – VNA and X-band waveguide

Results

Experimental tests evaluated reflection loss (RL) performance by comparing different material configurations in the geometric multilayer structure in two orientations: horizontal and vertical. The best result was obtained when conductive PLA was placed in the middle layer in vertical Direction with RL of -16 dB, as shown in Figure 2. This configuration improved electromagnetic wave attenuation, demonstrating strong potential for stealth applications.

The geometric layering played a crucial role in wave absorption. The honeycomb structure exhibited superior dispersion and impedance matching, enhancing absorption efficiency. Meanwhile, the triangular layer provided structural stability and further contributed to electromagnetic wave attenuation by improving wave dispersion.

The results also emphasize the importance of material distribution within the multilayer structure. Positioning conductive PLA in the middle layer optimizes wave interference and energy dissipation due to multiple reflections and wave dispersion, thereby reducing reflected signals. This approach holds promise for the development of lightweight, customizable, and cost-effective radar-absorbing materials.

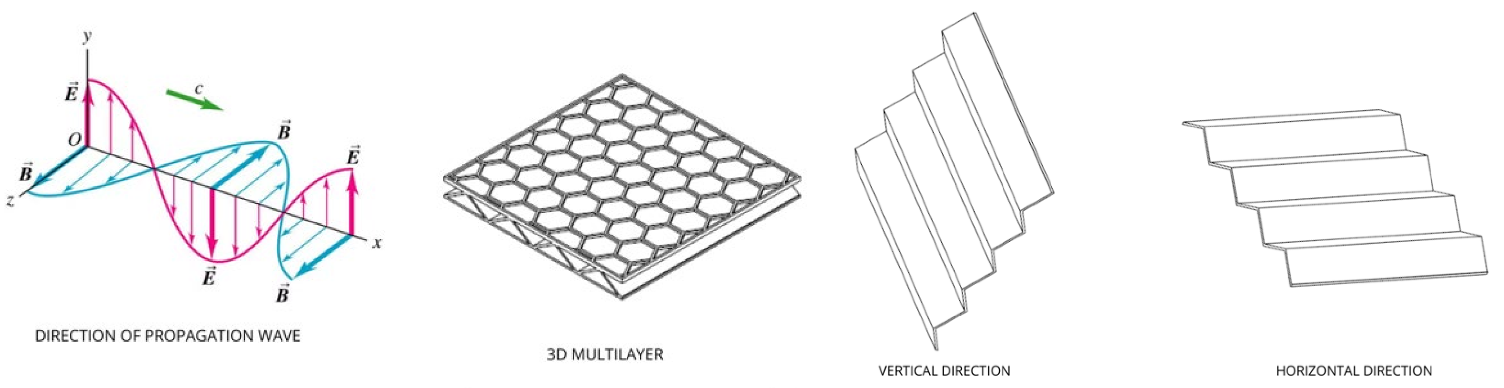

Figure 4 - Squematization of 3D multilayer measurement

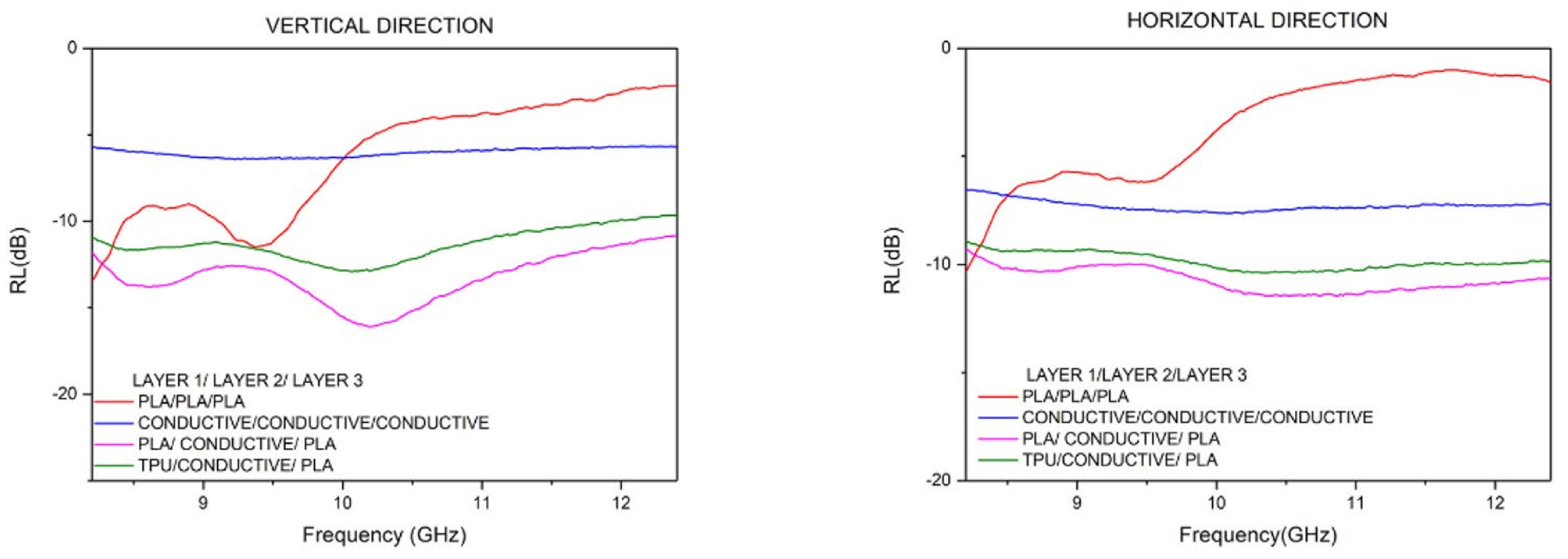

Figure 5 - RL Results by direction

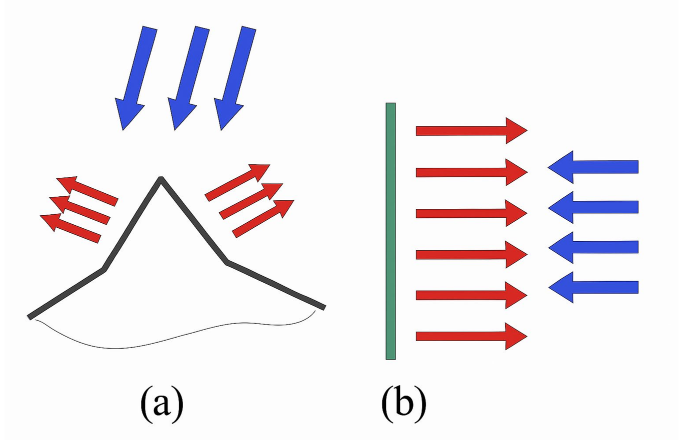

Figure 6 – (a) Electromagnetic wave attenuation on a triangular surface (b) Reflection on a planar surface.

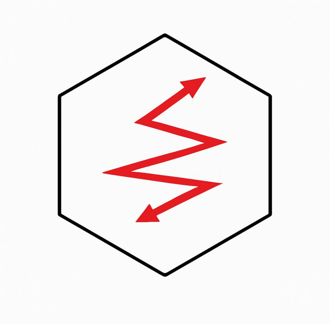

Figure 7 – Internal multiple reflections within a honeycomb cell.

Conclusions

In conclusion, this study demonstrates that 3D-printed geometric multilayer structures combining PLA or TPU with conductive PLA can effectively achieve significant radar wave attenuation. The configuration employing conductive PLA as the middle layer exhibited the best performance, achieving a minimum reflection loss of −16 dB. The improved absorption performance is primarily attributed to two synergistic mechanisms: (i) multiple internal reflections within the honeycomb structure, which extend the electromagnetic wave propagation path and enhance energy dissipation, and (ii) signal scattering induced by the triangular surface geometry, which disrupts the coherence of the reflected waves and reduces backscatter intensity. These mechanisms contribute not only to increased attenuation but also to better impedance matching with free space, minimizing wave reflection at the air-material interface. The results highlight the critical role of geometric design in tailoring the electromagnetic response, providing a robust strategy for the development of lightweight, customizable, and high-performance stealth materials for advanced radar-absorbing applications.

Acknowledgements

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