A study on the mechanical properties and microwave absorption performance of nickel-coated basalt fiber/aluminosilicate ceramic composite applicable to hypersonic vehicle

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Abstract

In this study, a microwave absorbing structure that can implement stealth performance in a hypersonic environment was proposed. Basalt fiber and aluminosilicate with excellent heat resistance were selected to manufacture microwave absorbing structures, and nickel electroless coating was performed on basalt fiber to modify electromagnetic properties. Using CST-MWS, an electromagnetic field commercial program, a microwave absorbing structure was designed in the X-Band (8.2 - 12.4 GHz), and a microwave absorbing structure was manufactured through the autoclave process. The prepared specimen was evaluated by measuring the mechanical properties and microwave absorption performance in room temperature and ultra-high temperature environments. As the temperature increased, the microwave absorption performance decreased, but the absorption performance did not change significantly. It was also confirmed that the compressive strength increased as the amount of KOH mol constituting the geopolymer increased.

Keywords (Tahoma 10 pt, bold): Hypersonic Flight, Ultra High Temperature, Ceramic Matrix Composite, Radar Absorbing Structure

1. Introduction

Hypersonic weapons systems that can be evaded while flying in and out of the atmosphere at a low altitude are less likely to be defended by current technology, so research and development of hypersonic technology is identified as a key area [1]. Hypersonic technology is expected to be a key technology in the future as it can avoid detection and defense due to its speed, mobility, and low altitude [2]. As a result, the U.S., Russia, and China, the largest military powers, are accelerating competition to develop weapons systems such as hypersonic missiles, submarines, and stealth.

Hypersonic flying vehicles are those that fly at speeds of at least Mach 5 and are exposed to ultra-high temperatures. To apply stealth technology in the hypersonic area, excellent heat resistance in ultra-high temperatures, structural functions in hypersonic environments, microwave absorption performance, and electromagnetic wave reflection area reduction technology are required. However, conventional microwave absorbing structures are unsuitable in ultra-high temperatures due to low thermal stability and oxidation resistance using polymer-based matrix materials. Therefore, it is necessary to study materials that can implement stealth performance in ultra-high temperature environments and microwave absorbing structures.[3]

In this study, a ceramic microwave absorbing structure with excellent heat resistance in an ultra-high temperature environment was designed and manufactured using nickel-coated basalt fiber and aluminosilicate, and mechanical properties and microwave absorption performance in a hypersonic environment were evaluated.

2. Design and Fabrication

In this study, Basalt fiber and Aluminosilicate were selected to implement a microwave absorbing structure that can exhibit microwave absorption performance in an ultra-high temperature environment. Basalt fiber consists of silicon dioxide ($Si0_2$) and aluminum oxide (Al_2O_3), which has excellent heat resistance, thermal conductivity, and superior tensile strength than glass fibers [4]. In addition, it has dielectric properties, so it can be applied as a stealth material. In this study, nickel electroless coating was performed to modify electromagnetic properties. The Aluminosilicate matrix has high strength and hardness [5], and it was produced by mixing metakaolin calcined at high temperatures with a geopolymer composed of K_2SiO_3 and KOH.

Before the design, an electromagnetic specimen, a nickel-coated basalt/aluminosilicate composite, was produced to optimize the microwave absorbing structure. It was manufactured through Hand lay-up and cured by an autoclave process, raising the temperature from room temperature to 80°C for 30 minutes and maintaining a pressure of 3 atm for 24 hours at 80°C.

The specimen produced by the above process measured the permittivity and permeability in the X-Band (8.2 - 12.4 GHz) using a free space measurement system. Based on the measured electromagnetic properties, commercial software MATLAB R2011b (MathWorks Inc., USA) derived the optimal thickness of the two-layer microwave absorbing structure that can exhibit excellent microwave absorption performance, and modeled and analyzed the two-layer microwave absorbing structure using CST Microwave Studio, a commercial electromagnetic field analysis program. Based on the results of the analysis, a two-layer microwave absorbing structure was produced.

3. Experimental

In this study, the microwave absorbing structure designed evaluated the mechanical properties and microwave absorption performance in an ultra-high temperature environment. It was measured at room temperature and ultra-high temperature for application to actual hypersonic stealth aircraft. A universal material tester and a heat chamber were used, and a compression strength test was performed according to the ASTM standard. In addition, the X-band (8.2 - 12.4 GHz) microwave absorption performance in room temperature and ultra-high temperature environments was measured using a free space measurement system and an ultra-high temperature heat chamber that can give an ultra-high temperature environment.

4. Results and Discussion

As a result of the measurement, a composite was manufactured by adjusting the amount of mol of KOH constituting the geopolymer to modify mechanical properties, and it was confirmed that the compressive strength increased as the amount of KOH mol increased. In addition, the microwave absorption performance measured using an ultra-high temperature heat chamber tended to decrease in the X-Band as the temperature increased, but the change was not significant. The absorption performance decreases as the temperature increases because the thickness of each layer of the microwave absorbing structure with excellent heat resistance changes due to thermal expansion, and the impedance matching characteristics change.

5. Conclusion

This study proposed a microwave absorbing structure that can be applied to hypersonic stealth aircraft using nickel-coated basalt fiber/aluminosilicate. Ceramic fibers and resins with excellent heat resistance and thermal conductivity were used, and nickel electroless coating was performed to modify electromagnetic properties. It was made into a two-layer structure to achieve excellent microwave absorption performance in an ultra-high temperature environment and the X-Band, and measured microwave absorption performance and mechanical properties to evaluate structural integrity. As the temperature increased, the microwave absorption performance decreased, but the absorption performance did not change significantly. It was also confirmed that the compressive strength increased as the amount of KOH mol constituting the geopolymer increased. Therefore, it was confirmed that the microwave absorbing structure proposed in this study is a promising structure that can be applied to a hypersonic environment.

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References

1. Son, H.S., Lee, H.I., Ko, D.G.: Hypersonic Weapon and national security. Journal of Aerospace System Engineering. 16(1), 56-69 (2022)

2. Sayler, K.M.: "Hypersonic Weapons: Background and Issues for Congress," Congressional Research Service (2019)

3. Jo, S.J., Choi, J.H.,: U.S. Navy efforts to counter hypersonic missiles. Defense and technology. 503, 64-79 (2021)

4. Sim, J.S., Park, C.W.: Characteristics of basalt fiber as a strengthening material for concrete structures. Composites Part B: Engineering. 36(6-7), 504-512 (2005)

5. Choi, K.S., Sim, D.Y., Choi, W.W., Shin, J.H., Nam, Y.W.: Ultra-high Temperature EM Wave Absorption Behavior for Ceramic/Sendust-aluminosilicate Composite in X-band. Composite research. 35(3), 201-215 (2022)