Multi-functional aramid/epoxy composite for stealth space impact shielding system

1. Introduction

Recently, approximately 30% of space structures including satellites have been increasingly used for military purposes such as reconnaissance, intelligence, surveillance, and early warning systems. The military use of stealth/spy satellites has encouraged many countries to monitor their enemies' satellites and to interface with their space missions; however, technology is actively being developed to hide the existence of stealth/spy satellites. Therefore, radar cross-section (RCS) reduction technology to absorb or scatter electromagnetic waves from other’s radar has become essential to the mission viability of stealth satellites. The RCS reduction technology is categorized into stealth shape design, radar-absorbing material, and radar-absorbing structure. Researchers recently developed a conical-shaped stealth satellite called the satellite signature suppression shield to reduce the RCS with regard to radar detection as a military target. Although this traditional RCS technique has so far successfully improved the survivability of stealth satellites, it is vulnerable to bi-static radar. Moreover, because this technique was designed to hide the structure of a satellite by adjusting its attitude in the direction of an anticipated threat radar, the satellite needs to change its attitude continuously to cope with the distributed ground stations. In this study, the electrical properties of aramid fabric with high strength and excellent stiffness were modified to realize a radar absorber via an RF magnetron silver-sputtering coating technique to protect the stealth satellite structure from the hypervelocity impact of micro-meteoroids and orbital debris; the novel design concept is shown in Fig 1. A new stealth space shielding system was developed for military purposes without increasing the impact shield thickness and having the stealth capability to absorb electromagnetic waves by the front bumper of a general whipple-shield system by considering the advantages of multi-functional composite materials.

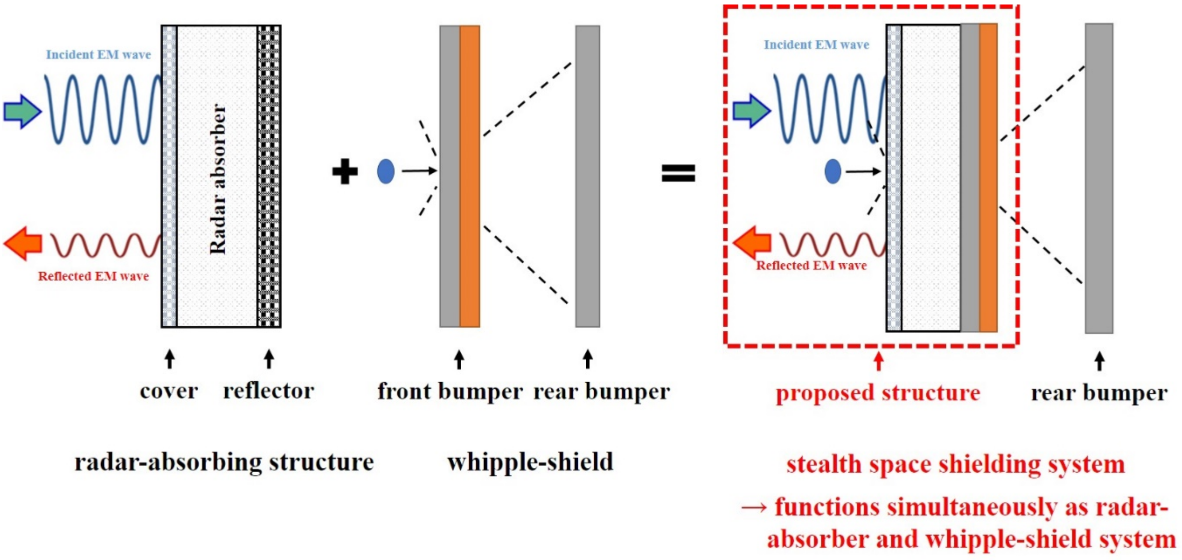

Fig 1. Stealth space shielding system composite with novel design concept.

2. Stealth performance

The proposed shielding composite was designed to cover a broad band from 2 to 18 GHz and was thin and lightweight compared to conventional stealth satellites.

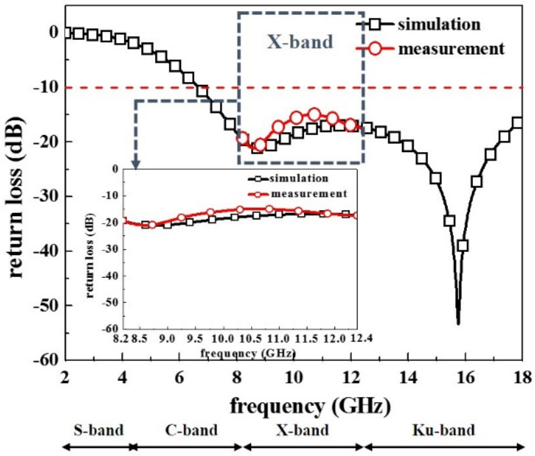

Fig. 2. Microwave absorption performance of proposed stealth space shielding composite.

Fig. 2 shows the microwave absorption performance of the composite simulation and measurement results. The simulation results of the proposed shielding composite demonstrated excellent microwave absorption performance with a broad bandwidth below -10 dB with one or more strong peaks from 6.65 to 18 GHz. The measured microwave absorption performance was in good agreement with the simulation result in the X band (8.2 to 12.4 GHz). Based on this result, the return loss measurement results confirmed that the stealth performance qualities of the proposed stealth space shielding system were verified.

3. Shielding performance

This section discusses how the silver coating affects the impact performance of the space stealth structure. The autoclave-fabricated specimens were tested for space shielding performance using a two-stage light-gas gun as shown in Fig. 3.

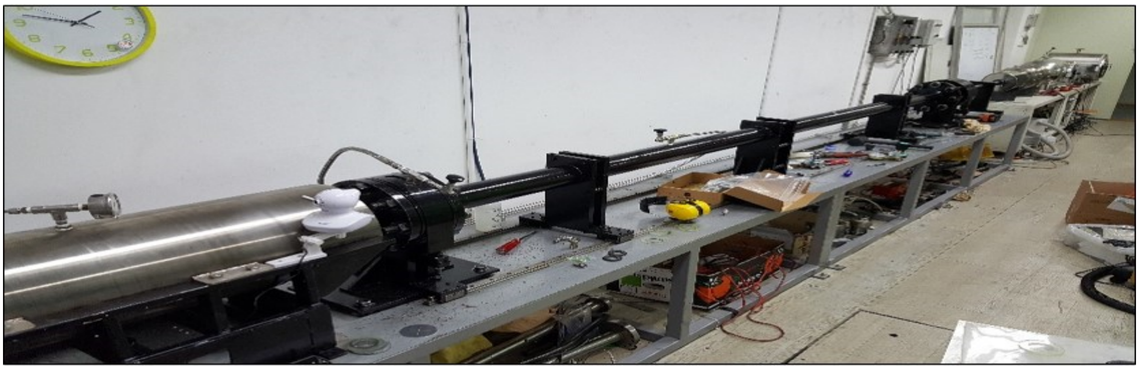

Fig. 3. Two-stage light-gas gun to measure impact performance of stealth space shielding

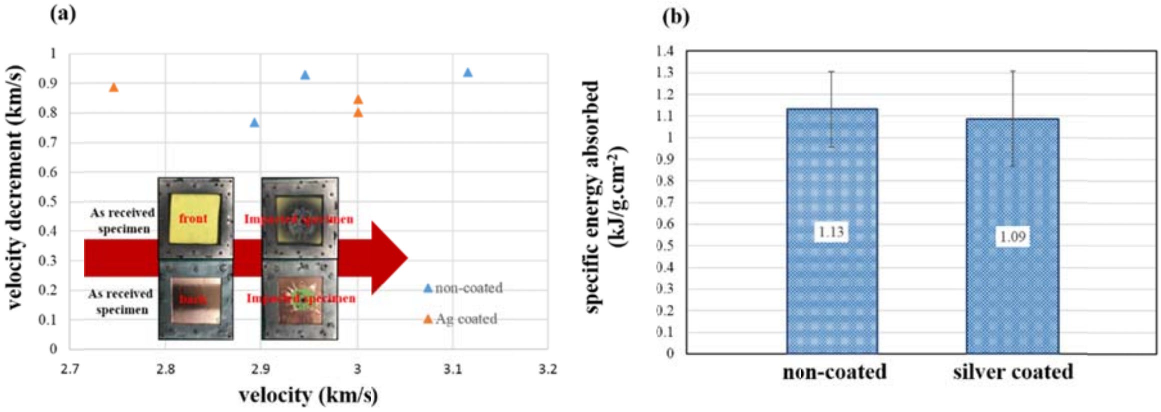

Fig. 4. (a) Velocity decrement of projectile after impact with non-coated and silver-coated aramid/epoxy composites, and (b) specific energy absorbed by non-coated aramid and silver-coated aramid/epoxy composites.

Fig. 4 (a) shows the velocity decrements of the projectiles for both the non-coated and Ag-coated aramid/epoxy composites. It can be seen that the velocity decrements were almost identical. The non-coated aramid/epoxy composites had an average velocity decrement of 877.98 m/s, whereas the Ag-coated aramid/epoxy showed a slightly lower velocity decrement of 845.18 m/s. This 3.73% decrease in velocity decrement could be attributed to variations in the areal density of the composites, small variations in the thicknesses of the laminates, specimen dimensions, and small errors during the experimental process. As shown in Fig. 4(b), the specific energy absorbed by the non-coated and the Ag-coated aramid/epoxy composite specimens were 1132.14 J/g.cm2 and 1086.89 J/g. cm2, respectively. The average specific energy of the laminate decreased by 3.99% for the Ag-coated specimens. This decrease in specific energy absorption was too small to be considered significant in reducing the overall performance of the shielding design for hypervelocity impact. Moreover, both specimens showed a similar kind of failure on the post-impact specimen. Thus, we can conclude that the Ag coating on the composite specimen has a minimal effect on the impact shielding performance.

4. Conclusion

In this study, a new stealth space shielding system design concept was proposed by combining a broadband radar-absorbing structure and an impact-shielding system. To achieve the broadband microwave-absorption performance without the use of a dielectric-loss material in a polymer matrix, electrical modifications of aramid fabric with respect to optimal dimensions were used via RF magnetron silver sputtering with various coating-time durations. The designed structure had exceptional microwave absorption performance at -10 dB from 6.65 to 18 GHz. To check the impact performance, hypervelocity impact tests were conducted on the silver-coated aramid/epoxy composite for speeds of 2.7 to 3.2 km/s. The impact energy absorption of the proposed composite demonstrated similar specific energy, type, and shape of failure when compared to the pristine aramid/epoxy composite. From a practical point of view, the newly proposed stealth space shielding composite has a potential application in military satellite systems.