Outer Wall Structure Design of Mars Exploration Vehicle for Radiation Shielding

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Abstract

Considering the high-pressure inside and the launch and Mars entry environment, the Rover cabin was based on the design of the ISS habitation module, and the skin-stringer structure design was proposed. In order to propose a realistic design of a cosmic radiation shielding Rover, UHMWPE composites were proposed as a Rover skin structure. The thermal environment while the Rover was being transported to Mars was reviewed through relevant documents, with the result that 125°C was set as the temperature for the space environment test. PUR and acrylic resin were selected as suitable matrix for UHMWPE composite through space environment tests. The SEM image confirmed that the microcracks of fibers and matrix increased after the space environment test. Therefore, it was predicted that the mechanical properties would deteriorate after the space environment. In the results of proton irradiation tests and OLTARIS analysis through elemental composition, UHMWPE composites showed cosmic radiation shielding performance comparable to PE. Based on conservative career effective dose limits (permissible dose limits) design specifications, the GCR dose on the surface of Mars is designed to expose astronauts to effective doses of 145 to 163 mSv/year, which is the limit dose for women between the ages of 35 and 40. Therefore, the thickness of UHMWPE composite as Rover outer wall was proposed to be 1 ~ 7.5 g/cm^2. It is expected that UHMWPE composites will be applied to future Mars exploration vehicles.

Key words. Composites, Space environment, Mars exploration vehicles, Cosmic radiation

1. Introduction

Humanity has much interest in exploration of Mars and the development of colonies on Mars, because the economic benefits of resources and the settlement of other planets can reduce the likelihood of human extinction. The United States (NASA) is planning the first manned mission to send astronauts to Mars and return to Earth in the 2030s. Also, Russia (Roscosmos) plans to send humans to Mars in the 2040s. The European Space Agency (EAS) has a long-term goal to send humans into space, but manned spacecraft have not yet been developed. EAS plans to send a robotic probe like ExoMars in 2022.

Mars is a planet almost the same size as Earth. Therefore, astronauts have to travel long distances to explore Mars. Apollo Lunar Roving Vehicle, Lunokhod, Sojourner, Spirit and Curiosity in Fig. 1 have demonstrated exploration capabilities beyond expectations, proving the need for surface vehicles for exploration of the planet. The Rover has many advantages over a stationary lander, making it widely used for exploration of Mars and the Moon. In manned planetary exploration, ground transport capabilities are critical to accomplishing a wide range of tasks, from building bases and transporting supplies to long-term explorations of tens of kilometers away.

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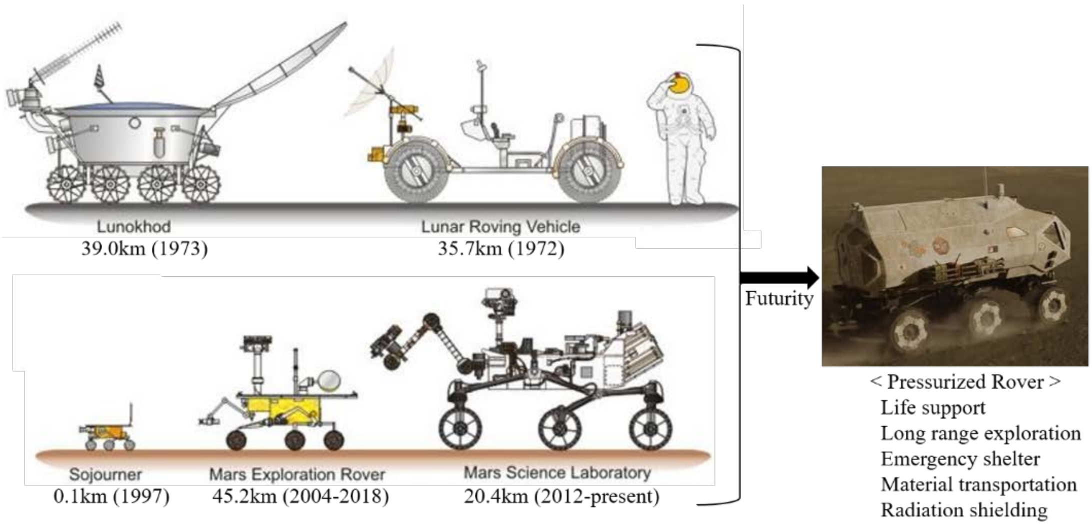

Fig 1. Rover used for planetary exploration

The lunar Rover has been the only moon exploration vehicle ever used. Lunar Roving Vehicle has a mass of 210 kg and is in an unpressurized open form. The frame is 3.1 meters long and the wheelbase is 2.3 meters long. The frame is made of aluminum alloy 2219 tube welding assembly and consists of a three-part chassis that is hinged in the center and can be folded into the Lunar Module quad 1 bay [1].

A pressurized Rover in Fig. 1 will be used as a mobile base for future Mars exploration. The pressurized rover provides cosmic radiation shielding, life support and can move long distances with many supplies in a comfortable environment outside the space suit.

From space heritage, aluminum, titanium, and CFRP have been proposed for pressurized rover materials. Several pressurized rover designs have been proposed [1], but no studies have mentioned space radiation shielding as a rover material. This study will be the first to discuss pressurized rovers for space radiation shielding and heat shielding.

2. Proton irradiation tests

To compare the proton shielding performance of PE, PE/PUR, and PE/acrylic resin, 100MeV proton irradiation (TR102 in Korea Multi-purpose Accelerator Complex, Gyeongju, Republic of Korea) tests were performed in Fig. 6. In the GCR, the proton 100MeV is the highest flux [4], so the experiments were conducted with the proton 100MeV energy (shielding properties of protons and heavy ions are almost the same). Since 14.4Gy corresponds to a 10-year dose behind aluminum thickness 2 mm (payload fairing thickness), 14.4Gy was chosen as the experimental dose (calculated as OLTARIS).

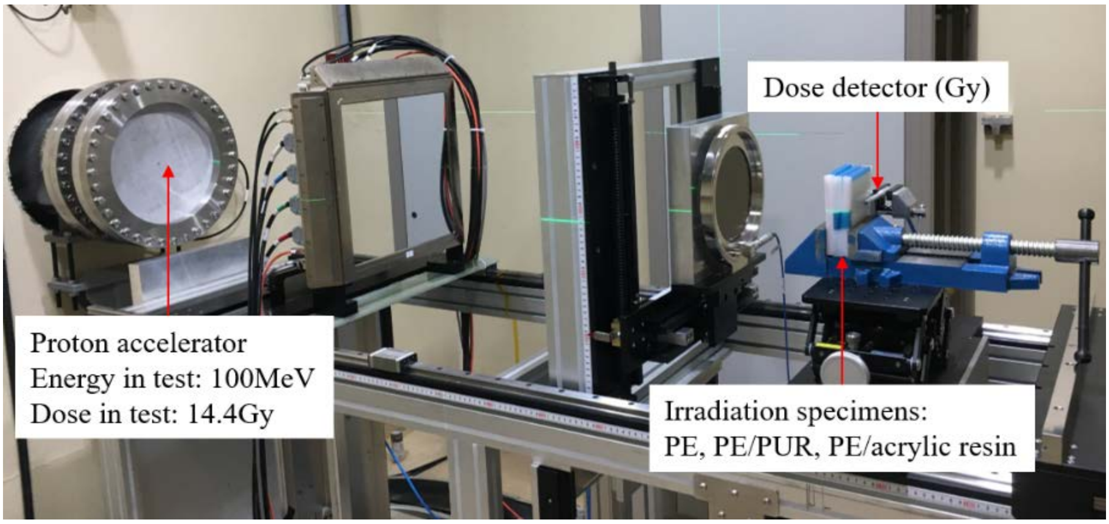

Fig 2. Proton irradiation test setting

After the protons is irradiated from the accelerator, the dose is measured after the proton passes through the specimen. The shielding doses of PE, PE/acrylic resin, and PE/PUR with similar areal densities were measured as shown in Fig. 7. From the results of the experiment, we were able to observe the Bragg peak. From the shielding areal density, it can be seen that the proton shielding performance is in the order of PE, PE/ acrylic resin, PE/PUR. However, the proton shielding performance of UHMWPE composites and PE was almost the same. Therefore, it is estimated that UHMWPE composite and PE will have similar cosmic radiation shielding performance.

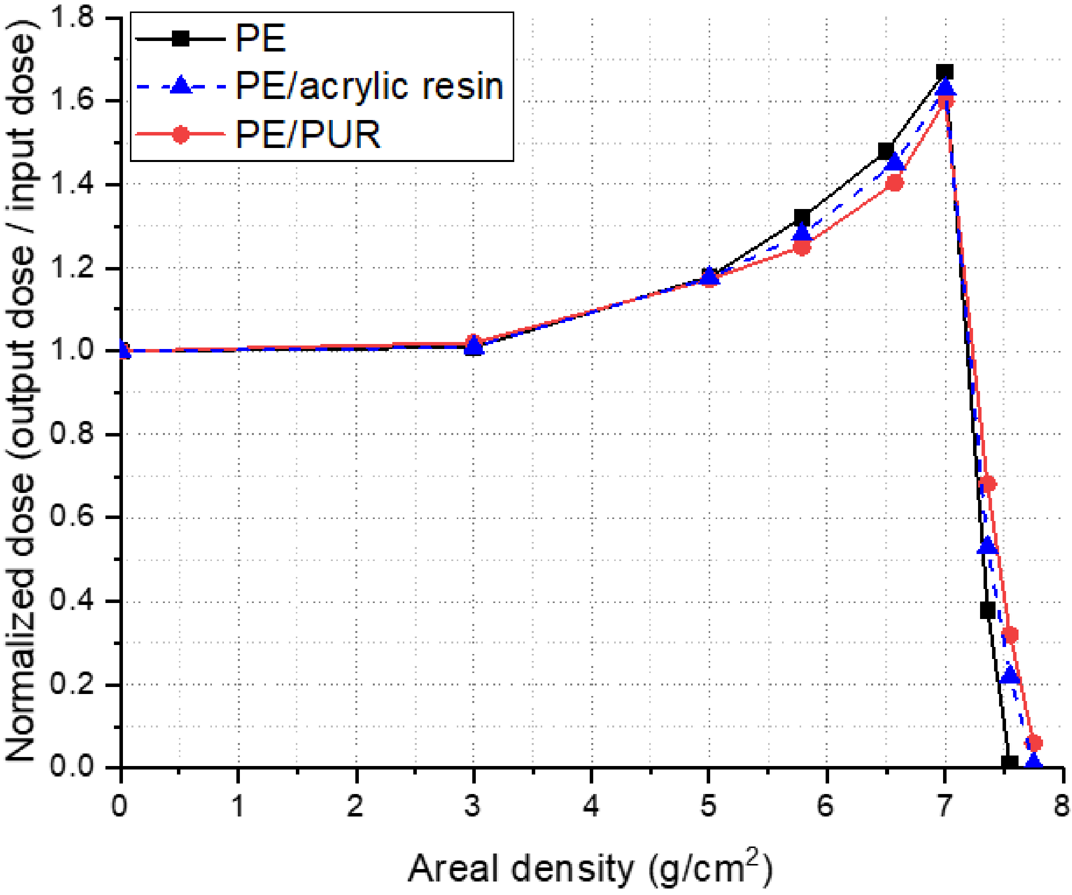

Fig 3. Proton irradiation test results

3. Composition of UHMWPE composite

Elemental composition of UHMWPE composites is required for OLTARIS analysis. In the UHMWPE composite, the composition of oxygen was measured using the FLASH2000 elemental analyzer, and the composition of carbon, hydrogen, and nitrogen was measured using the elemental analyzer FlashEA1112 (Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea).

Materials with high hydrogen content are the basic principle of cosmic radiation shielding. As shown in Table 2, the difference in hydrogen content between UHMWPE composites and PE is less than 2%. UHMWPE composites have a hydrogen content comparable to PE. For that reason, it can be determined in the proton irradiation tests that the shielding performance of PE and UHMWPE composites was similar.

Table 1. Composition of UHMWPE composite

Elements	Composition of PE/PUR (measure value)	Composition of PE/acrylic resin (measure value)	Composition of PE (theoretical value)
Hydrogen	64.85%	65.88%	66.66%
Carbon	32.46%	32.85%	33.33%
Nitrogen	0.51%	0.19%	-
Oxygen	1.48%	0.38%	-

4. OLTARIS verification & Radiation model selection

The NASA literature [5] that calculated the GCR radiation in Mars surface was used to validate that OLTARIS analysis was consistent. As shown in Table 3, NASA literature and Curiosity's Mars surface dose measurements are slightly different. The historical solar values used in this study have been slightly modified from NASA literature values to match measured Curiosity dose values. As a result, the calculated Mars surface dose value at OLATRIS could be changed to 232 mSv/year.

The Badhwar-O'Neill model has been used for a long time to describe the GCR environment encountered by astronauts and sensitive electronics in space [28]. The most recent version of the GCR model, Badhwar-O'Neill 2014, calibrated with available measurements to reduce particle and critical energy model errors for astronaut exposure [28]. Therefore, unlike the NASA literature, the most recent version of the GCR model, Badhwar-O'Neill 2014, was used in this study.

Table 2. Mars surface radiation model

	NASA literature [5]	Model used in this study	Curiosity's dose measurements [3]
GCR model	Badhwar-O'Neill 2010	Badhwar-O'Neill 2014	7 August 2012 ~ 1 June 2013
Historical solar	Solar modulation parameter	Slightly modified solar modulation parameter	
Mars atmosphere model	Mars Climate Database (MCD) model (Millour et al. 2008)	Solar longitude: 150.6°, Mars Latitude: −4.6° N, Mars Longitude: 137.4° E 05:18 UTC	
Quality factor	ICRP60	-	
Human phantom	FAX (Female Adult voXel) (Kramer et al. 2004)	-	
Surface equivalent dose	239mSv/y	232mSv/y	232mSv/y

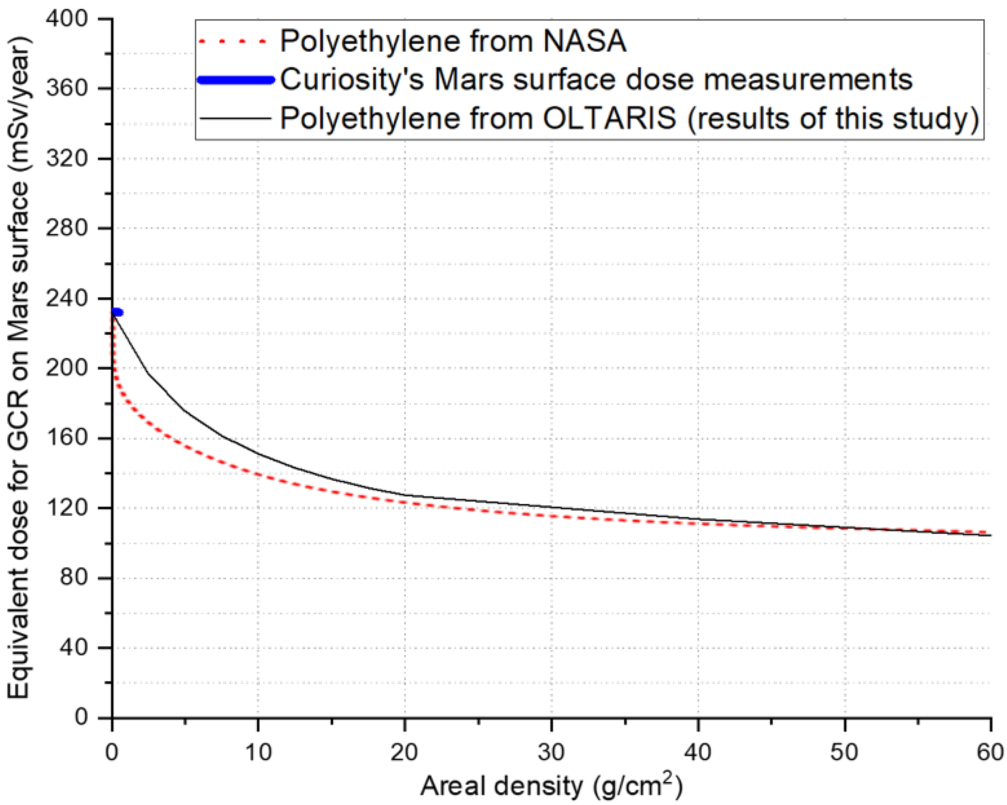

Fig 4. Proton irradiation test results

Using the model in Table 1, dose versus areal density of PE in a Mars surface was calculated and compared to the NASA literature. As shown Fig. 8, the radiation model of this study is a more conservative model than NASA literature.

5. Conclusion

Considering the high-pressure inside and the launch and Mars entry environment, the Rover cabin was based on the design of the ISS habitation module, and the skin-stringer structure design was proposed. In order to propose a realistic design of a cosmic radiation shielding Rover, UHMWPE composites were proposed as a Rover skin structure. The thermal environment while the Rover was being transported to Mars was reviewed through relevant documents, with the result that 125°C was set as the temperature for the space environment test. PUR and acrylic resin were selected as suitable matrix for UHMWPE composite through space environment tests. The SEM image confirmed that the microcracks of fibers and matrix increased after the space environment test. Therefore, it was predicted that the mechanical properties would deteriorate after the space environment. In the results of proton irradiation tests and OLTARIS analysis through elemental composition, UHMWPE composites showed cosmic radiation shielding performance comparable to PE. Based on conservative career effective dose limits (permissible dose limits) design specifications, the GCR dose on the surface of Mars is designed to expose astronauts to effective doses of 145 to 163 mSv/year, which is the limit dose for women between the ages of 35 and 40. Therefore, the thickness of UHMWPE composite as Rover outer wall was proposed to be 1 ~ 7.5 g/cm^2. It is expected that UHMWPE composites will be applied to future Mars exploration vehicles.

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