Evaluation of Environmental Protection Garments (EPG) Shell Textiles for Lunar Exploration Mission

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Astronauts are not prepared for extended lunar exploration missions because of regolith (lunar dust) that is a mixture of tiny shards of glass and rocky debris that were produced by millions of years of meteorite impacts (Keesey, 2019). Due to regolith's electrostatic charge, they adhere to the suit when the astronauts are outside and are released inside when the suit is taken off (Dombrowski et al., 2022), affecting the operability of equipment in the vehicle causing false instrument readings, seal failures, or clogging of mechanisms (Gaier et al., 2012). Once the dust is in the habitat, potential health effects are lunar hay fever, DNA degradation, and long-term respiratory problems (Wells, Bussey, Swets, & Leachman, 2023).

The Environmental Protection Garments (EPG) shell fabric is Orthofabric: a two-layer plain weave with Gore-tex on the face and Nomex and Kevlar on the back. The woven structure of Orthofabric determines their dust resistance because the intra-yarn gaps allow dust to penetrate and the face-to-back ties of Orthofabric create voids in the face allowing dust adhesion (Dombrowski et al., 2022). It was found that the combination of Shear Thickening Fluid (STF) and superhydrophobic coatings increased Orthofabrics puncture force by 354% and dust adherence was reduced by over 90% (Dombrowski et al., 2022). Gaier, Meador, Rogers, and Sheehy (2009) conducted regolith simulant tests and found that Tyvek did not allow any dust to penetrate because its non-woven paper structure was dense enough to block dust. However, Tyvek is combustible and does not meet NASA's flammability requirements for the EPG shell. The EPG shell fabric must withstand lunar surface temperatures from -178°C to 124°C and in the permanently shadowed regions (craters) the temperatures could be as low as -233°C (Flores-Daley and Jones, 2022) as well as meet other material requirements like flame retardance, low-outgassing, abrasion resistance and strength.

The purpose of this research study was to explore nonwoven fabrics for future EPG shell that would eliminate dust penetration problems and improve dust abrasion properties while maintaining similar strength to Orthofabric and meeting the other material requirements. This research also explored the effects of STF and superhydrophobic coatings on fabrics performance.

The researchers acquired two 14 oz polyimide needle-punched nonwoven fabrics from Alberrie (Barrie, ON, Canada): sample 1 is a self-supported nonwoven and sample 2 is a hybrid scrim supported nonwoven. Polyimide nonwoven fabrics were chosen because polyimide fibers have high heat resistance, good thermal and chemical stability, good wear resistant, and excellent mechanical and insulating properties in harsh environment (Kumar, Malaval, Antonov, & Zhao, 2020). The researchers tested the comfort and mobility properties (thickness, air permeability, stiffness/softness), durability properties (tensile strength, abrasion resistance), and dust properties (dust penetrated, dust adhered) of the two nonwoven fabrics, and Orthofabric neat and treated with STF and superhydrophobic coatings. Thickness was tested using a portable gauge with 10 replications. The air permeability was measured by an Automatic Air Permeability Tester (Aveno Technology Co., China) following ASTM D737 standard with ten replications. The stiffness/softness was measured by a Handle-o-meter (Thwing-Albert, West Berlin, NJ) following ASTM D6828 standard with four replications. The tensile strength was measured using a H5KT Benchtop Materials Tester (Tinius Olsen, Horsham, PA) following ASTM D5034 standard with three replications. The flex and abrasion resistance was measured using a Universal Wear Tester (SDL Atlas, Rock Hill SC) following ASTM D3885 standard (weights used on the back and front rack were 8 lb and 2 lb, respectively) with four replications. The dust test was performed using a sieve shaker dust testing method as described in reference (Dombrowski et al., 2022). The textiles were placed in a Suntest XLS+ (Atlas Material Testing Technology, Mt. Prospect, IL) for 336 hours and a dosage of 462642 kj/m^2 to simulate extraterrestrial UV exposure and its effect on abrasion properties of the samples.

Table 1. Textile testing results

Sample		Weight (gsm)	Thick-ness (mm)	Air Permeability (mm/s)	Stiff-ness (g)	Tensile Strength (N)	Flex and Abrasion Resistance (cycles until rupture)		Dust Penetration (gsm)	Adhered Dust (gsm)	
							Before sun exposure	After sun exposure		Post Dust Test	Post Adherence Test
Ortho-fabric	Warp	491	0.657 ± 0.01	282.04 ± 20.04	97.81 ± 5.27	4024 ± 34.18	14374.5 ± 2594.05	8376.67 ± 1192.41	87.91	85.28	17.54
	Filling					3521.33 ± 48.06	11235.5 ± 2291.21	10070.67 ± 3450.39			
Treated Ortho-fabric	Warp	545	0.677 ± 0.015	162.9 ± 12.37	-	-	11234.67 ± 1306.13	5230 ± 66.05	26.31	22.58	0.87
	Filling					-	17654.33 ± 4180.64	8428.5 ± 137.89			
Nonwoven 1		475	3.049 ± 0.129	386.61 ± 11.53	-	1167.00 ± 36.17	277.75 ± 12.12	155 ± 9.54	0	453.60	-
Nonwoven 2		475	2.218 ± 0.032	298.12 ± 20.31	455.56 ± 19.14	2592.00 ± 52.92	3108.25 ± 346.63	1380 ± 174.652	0	155.88	104.80
Treated Nonwoven 2		782	2.396 ± 0.039	222.62 ± 17.96	-	-	1776 ± 95.51	1197.333 ± 86.488	0	137.90	78.49

The results (Table 1) showed the nonwoven scrim supported sample 2 out performed the self-supported sample 1 for the durability tests. Neat Orthofabric and nonwoven sample 2 had similar air permeability but neat Orthofabric had a better tensile strength and flex and abrasion resistance. Nonwoven 2 is thicker and hence is stiffer than Orthofabric. After sun exposure, all samples' flex and abrasion resistance results decreased by around 50%, indicating fabrics' strength is affected by solar radiation. When treated with STF and superhydrophobic coatings, the fabric's strength properties were less affected by UV exposure. For the dust test, Orthofabric had dust penetrate but nonwoven 2 did not. However, nonwoven 2 had more dust adhere to the sample due to its rough surface geometry that binds dust via physical trapping. The treatments improve dust penetration and dust adhesion properties for both Orthofabric and nonwoven 2 fabrics, but treated Orthofabric still has dust penetration.

In conclusion, scrim supported polyimide nonwoven (sample 2) has good dust resistance. It has the potential to meet NASA's material requirements if their construction is altered to increase their durability properties.

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