

**MARTIAN SOIL SIMULANT FOR LARGE-SCALE FIELD EXPERIMENTAL RESEARCH (EXOMARS).**

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**Introduction:** According to Roskosmos and ESA plans, 2020 mission of ExoMars programme consists of rover and surface platform. Preliminary research on martian surface of supposed target areas (Oxia Planum and Mawrth Vallis) is necessary for successful landing of the module. This investigation includes exploration of physical and physico-mechanical soil properties which is based on new martian soil simulant.

**Materials and methods:** Spirit, Opportunity, Pathfinder, Viking missions provide in-situ data on physical and physico-mechanical properties of martian soils which became a basis of our research [1]. We created 4 mixtures of easy-to-find desintegrated components such as quartz sand, fly-ash and ash-slag waste (ASW) based on quantitative estimates of the prevalence of different types of terrain (Tables 1 a-c, 2 a-d).

Table 1a. Martian soil properties (density and particle size distribution) expected at the landing sites of Oxia Planum and Mawrth Vallis. Chemical composition of all components (except clay) are basalt-like. The percentage of soil components was estimated by analysis of high-resolution images of the sites [1, 2]

Soil components	Density, g/cm <sup>3</sup>	Grain size, mm	Percentage, %	
			Oxia	Mawrth
Silt	1-1.3	0.001-0.01	2-7	2-7
Sand	1.1-1.3	0.06-0.2	22-27	8-13
Crusty to Cloddy	1.1-1.6	0.005-0.5	32-37	22-27
Blocky	1.2-2.0	0.05-3	26-31	20-25
Pebbles	2.6-2.8	2.0-2000	5-10	13-18
Clay	1.5-1.6	<0.001	0-3	20-25

Table 1b. Martian soil properties (cohesion and angle of internal friction) expected at the landing sites of Oxia Planum and Mawrth Vallis [1]

Soil components	Cohesion, kPa	Angle of internal friction, degree
Silt	0-3	15-21
Sand	0-1	30
Crusty to Cloddy	0-4	30-40
Blocky	3-11	25-33
Pebbles	1000-10000	40-60

Table 1c. Composition of soil simulants, %

Mixture	Quartz sand 0.5-1.2 mm	Quartz sand 0.19-0.23 mm	Fly-ash	Ash-slag waste (ASW)
1	33	28	7	32
2	25	15	30	30
3	40	40	10	10
4	-	50	20	30

Data on other physical and physico-mechanical properties of real martian soil were used as requirements for appropriate soil simulant:

- Grain-size distribution;
- Dry and particle density;
- Cohesion;
- Angle of internal friction;
- Moisture content.

Physico-mechanical properties were obtained in tri-axial and direct shear tests.

**Results:** According to results of our experiments, mixture #2 (Table 1c) seems physico-mechanically similar to martian soil. Its density in loose state is 1.3 g/cm<sup>3</sup> (Table 2d), that is close to upper bound of martian silt and sand soils' density estimations (~1.3 g/cm<sup>3</sup>) (Table 1a). The mixture's density in compact state is 1.55 g/cm<sup>3</sup> (Table 2d), which corresponds to the density range for clay, crusty to cloddy and blocky martian soil density intervals (Table 1a). Low moisture of the mixture is typical for upper part of martian soil in ExoMars mission's target areas [3]. Besides, stiffness modulus, elastic modulus, bearing capacity, dynamic elastic modulus, dynamic modulus were measured, but there are no estimates of these properties of real martian soil.

We propose Mixture #2 for drop-tests of ExoMars landing module.

Table 2a. Physical properties of components (grain-size distribution)

			Quar tz sand 0.5- 1.2 mm	Quar tz sand 0.19- 0.23 mm	Fly- ash	Ash- slag waste (AS W)	
Grain-size distribution (mm) in soil simulants in weight %	Cobble	>10	0.0	0.0	0.0	2.2	
		Pebble	10-5	0.0	0.0	0.0	1.6
			5-2	0.0	0.0	0.0	2.1
	Sand	2-1	24.0	0.0	0.0	1.9	
		1-0.5	72.0	1.0	0.0	1.4	
		0.5-0.25	2.6	36.0	0.6	1.7	
		0.25-0.1	0.8	62.3	5.9	5.0	
		0.1-0.05	0.5	0.6	42.7	22.5	
		Dust	0.05-0.01	0.1	0.1	48.0	45.6
	0.01-0.005		0.0	0.0	1.7	10.6	
	0.005-0.002		0.0	0.0	1.1	5.0	
	<0.002		0.0	0.0	0.0	0.6	

Table 2b. Physical properties of soil simulants (grain-size distribution)

			Mixtures			
			1	2	3	4
Grain-size distribution (mm) in soil simulants in weight %	Cobble	>10	0.0	0.0	0.0	0.0
	Pebble	10-5	0.0	0.0	0.0	0.0
		5-2	0.3	0.2	0.1	0.1
	Sand	2-1	11.2	7.4	9.6	0.8
		1-0.5	25.2	21.2	33.2	1.2
		0.5-0.25	8.1	4.6	11.6	12.7
		0.25-0.1	22.0	16.9	26.6	36.0
		0.1-0.05	7.9	12.5	8.3	10.7
	Dust	0.05-0.01	18.5	35.1	7.8	33.6
		0.01-0.005	5.4	1.0	2.0	4.4
		0.005-0.002	1.5	1.0	1.0	0.6
		<0.002	0.0	0.0	0.0	0.0

Table 2c. Physical properties of components

		Quar tz sand 0.5- 1.2 mm	Quar tz sand 0.19- 0.23 mm	Fly- ash	Ash- slag wast e (AS W)
Moisture content,%	W	0.0	0.1	0.1	14.3
Particle density, g/cm <sup>3</sup>	$\rho_s$	2.65	2.65	2.48	2.24
Dry bulk density, g/cm <sup>3</sup>	Com- pact	$\rho_{d \max}$	1.44	1.58	1.47
	Loose	$\rho_{d \min}$	1.20	1.38	1.12

Table 2d. Physical and physico-mechanical properties of soil simulants

			Mixtures			
			1	2	3	4
Moisture content,%	W		0.5	0.4	0.2	0.5
Particle density, g/cm <sup>3</sup>	$\rho_s$		2.54	2.48	2.61	2.50
Dry bulk density, g/cm <sup>3</sup>	Com- pact	$\rho_{d \max}$	1.69	1.55	1.85	1.57
	Loose	$\rho_{d \min}$	1.44	1.30	1.59	1.32
Cohesion, MPa	c		0.011	0.007	0.036	0.031
Angle of internal friction, degree	$\varphi$		24	25	28	25
Stiffness modulus (in stress range 0.1-0.2 MPa), MPa	E		12.7	5.6	18.7	10.6
Elastic modulus, MPa	$E_y$		-	57.3	-	67.5
Bearing capacity, MPa	$E_{bc}$		0.38 5	0.33 2	0.38 4	0.45 1
Dynamic elastic modulus, MPa	$E_d$		115. 2	248. 9	117. 6	148. 5
Frictional coeffi- cient	tg $\varphi$		0.44 5	0.45 8	0.52 5	0.47 2
Dynamic modu- lus,MPa	$E_{vd}$		77.6	52.5	68.6	57.2

**References:** [1] Golombek M.P., Haldemann A.F.C., Simpson R.A., Fergason R.L., Putzig N.E., Arvidson R.E., Bell III J.F., Mellon M.T. Martian surface properties from joint analysis of orbital, Earth-based, and surface observations // The Martian surface: Composition, mineralogy and physical properties / Ed. Bell III J.F. Cambridge Univ. Press, 2008. P. 468–498. [2] Ivanov M.A., E.A. Grishakina, A.A. Dmitrovskii, E.M. Sorokin, V.Y. Makovchuk, A.V. Uvarova, E.A. Voznesensky, M.S. Nikitin, E.A. Sentsova, and E.N. Slyuta. ExoMars landing sites in OxiaPalus and MawrthVallis: geological characterization // The Ninth Moscow Solar System Symposium, Moscow, Russia, 8-12 October 2018. P. 243-245. [3] Mitrofanov I.G., Litvak M.L., Kozyrev A.S., Sanin A.B., Tret'yakov V.I., Grin'kov V.Yu., Boynton W.V., Shinohara C., Hamara D., Saunders S. Soil water content on Mars as estimated from neutron measurements by the HEND instrument on board the 2001 Mars Odyssey spacecraft // Sol. Syst. Res. 2004. V. 38. № 4. P. 253–265.