THE IMPACT OF ABRASION RESISTANT MATERIALS ON PERFORMAMANCE AND TOOL LIFE OF LUNAR SURFACE EXPLORATION AND MINING UNITS: AN EXPERIMENTAL STUDY.

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Introduction: From the beginning of space activities related exploration of the lunar surface, one issue has been frequently mentioned, but rarely pursued in quantitative measurement, and that is "abrasivity of regolith". The susceptibility of mining and drilling equipment to abrasion wear during lunar surface exploration and subsequently moving of surface regolith has received little attention in the ISRU community so far. The moon's surface is covered with loose materials such as boulders, cobbles, pebbles, and lunar soils, which are generally recognized as lunar regolith [1]. Because the lunar soil is very fine, with particle sizes ranging from 40-130 µm it is commonly described as dust [2]. Some minerals, such as arnothite, bytownite, labradorite, and fayalite, are abundantly found in the lunar regolith, along with glass that are common minerals of basaltic rocks. The brittle nature and sharp edges of these hard minerals result in abrasive dust [3-5]. During extravehicular activities (EVA) on the moon, astronauts have encountered the abrasive nature of lunar dust, which has caused damage to their equipment and spacesuits on several space missions [6]. Based on the observed nature of lunar dust particles Dust Management Project (DMP) under the Exploration Technology Development Program (ETDP) ranked abrasion in lunar exploration as a highly important aspect to evaluate the impact on equipment with moving parts for future lunar surface systems (LSS) by the NASA created [7].

However, the term "abrasive" seems to have been used in general perception and not in the right context for assessment of tool wear. Despite the significant threat to mission success posed by the abrasive properties of lunar regolith, the testing methodologies and techniques currently employed suffer from notable limitations.

Due to the exuberant mission launched in 2005 by NASA through the in-situ resource utilization (ISRU) program to extract and use lunar resources on-site [8], researchers are making efforts to tackle multidisciplinary challenges including the abrasive nature of lunar dust. Researchers are investigating existing dust mitigation techniques and attempting to quantify abrasion with lunar regolith using novel techniques aligned with standard ASTM tests [7]. The Earth Mechanic Institute (EMI) at the Colorado School of Mines (CSM) is collaborating with Technogenia Lasercarb Oklahoma Inc (TLOI) to evaluate the effectiveness of abrasion-resistant materials, i.e. laser cladded tungsten carbide (LCTC), against lunar simulants to develop a practical option for lunar excavation technology for future LSS.

This study employs the Soil Abrasion Index (SAI) test machine, which allows for examination of accelerated wear to offer a quantitative measure of wear on various tooling materials. The study consists of several experiments aimed at replicating excavation conditions using two lunar simulants, including Mare and Highland. The objective of this limited study was to quantify abrasion using steel with a hardness of 17 HRC and compare it with abrasion-resistant materials commonly used in terrestrial excavation processes, and those produced by [2]Technogenia. The results and findings provide valuable insights into the durability of the selected wear-resistant materials against lunar materials and their potential application in future LSS activities.

Experimental Setup: The SAI test machine comprises six main components: a material chamber with a diameter of 350mm and a height of 450mm, a drive unit with a 3.7kW electric motor, a three-blade propeller with a specific pitch angle, covers which can be made of target materials, load cells to measure torque force and rotation controller unit as illustrated in Figure 1. Further details on the various components and materials can be found in the literature [2-9].

Figure 1 Components: Soil Abrasion Test Machine

To conduct a test, the material chamber is filled up with the target material. Metal covers, either steel or infused with abrasion-resistant materials, are attached to the three-blade propeller with a 10° pitch angle and then submerged into the material of choice up to the mid-height (150 mm). The propeller is run at selected rotational speed, i.e. 60 rpm, for selected time. The pitch angle of the propeller progressively compacts the material to create high contact stresses to predict the long-term performance of target materials and mimic accelerated wear conditions. The metal covers are weighed before and after testing at selected time interval, typically 5, 10, 15, 30, and 60 minutes. To establish a baseline for the abrasion, steel covers with an HRC 17 are used against CSM sands, and comparisons with other target materials, such regolith allows one to compare the abrasivity of the regolith with reference soil. Alternatively, the same soil can be used in testing and covers to change, allowing for evaluation of performance of selected tooling materials in given soil/regolith. In this study, all experiments were conducted using the same test procedure.

Materials and Test Matrix: Two lunar simulants of Lunar Mare Type Simulant (LMT-1 from a basaltic feedstock as of JSC-1A sourced from Merriam Crater in Arizona) and Lunar Highlands Type Simulant (LHT-1) produced by EMI, along with a reference sand were tested to quantify abrasion against selected tooling materials.

Abrasion Resistant Materials. Selected soil and simulants were tested against steel covers of HRC 17 and 43, Material-1 HRC 64 and Material- 2 - HRC 45 (matrix) / HV 0.2 3000 (WC – W2C) produced by Technogenia. Material 1 HRC 64 is Fe based type of hardfacing using martensitic matrix with dispersed Vanadium Carbide. It was attached on the steel covers for testing in SAI test setup. Similarly, Material-2 - HRC 45 (matrix) / HV 0.2 3000 (WC – W2C) was a Ni based type of hardfacing consisting of Ni matrix mixed with spherical cast tungsten carbide which was attached to the steel covers for testing.

Test Matrix. An initial test matrix was developed for testing of selected tooling materials in simulants and reference soil type to assess abrasion and establish a baseline for performance of these materials in selected geologic settings. The matrix is presented in the **Table 1**.

Results and Discussion: Results of the testing are illustrated in Fig 3 and 4;

Table 1 Test Matrix

Base Material	Target Materials (Incl Abrasion Resistant)	Number of Tests
CSM Sand	Steel HRC-17	1
	Steel HRC 43	1
	Material -1 HRC - 64	1
	Material-2 HRC 45	1
LHT-1	Steel HRC-17	1
	Steel HRC 43	1
	Material -1 - HRC - 64	1
	Material- 2	1
LMT -1	Steel HRC-17	1
	Steel HRC 43	1
	Material -1 HRC - 64	1
	Material- 2	1

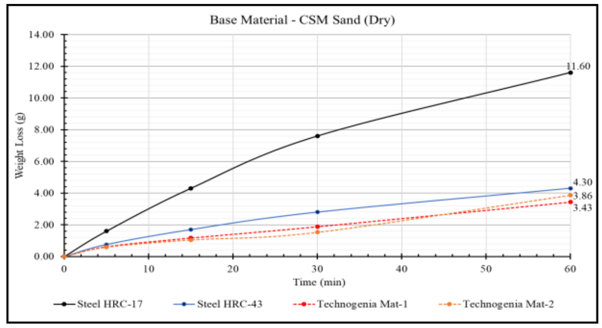

Figure 3 Soil Abrasion Test Results - CSM Sand

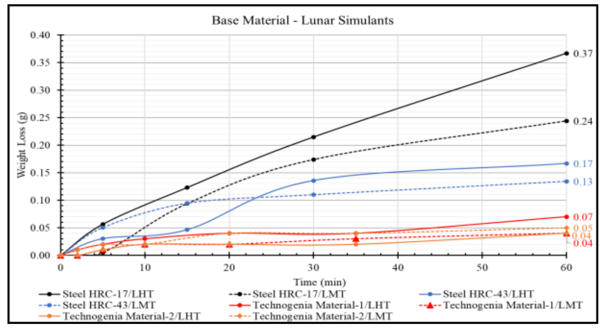

Figure 4 Soil Abrasion Test Results - Lunar Simulants

Discussion. The result of testing indicate that abrasion-resistant materials outperform steel products across all geological materials. In these charts, lower numbers mean lower wear and are more desirable. When comparing the same tooling materials in different soil types, higher measured wear means higher abrasivity of the soil and shorter life of the tool in that geomaterial. The LHT-1 appears to be more abrasive than the LMT-1, making EVA on highlands more challenging necessitating more cautious equipment handling. Material 2 is found to be more resistant to wear than material 1. It should be noted that the performance observed in this study is limited to the excavation of loose materials in powder form. Additional study is needed to verify the performance of wear resistant tooling materials in soil/regolith with different particle size distributions or when dealing with hard frozen regolith. Nevertheless, the results suggest that wear-resistant materials have potential for offering extended life of tools to be used on excavation systems or drilling bits for lunar exploration to avoid loss of efficiency and need for frequent maintenance and replacement.

Conclusions: The results of the limited study demonstrate that wear-resistant materials such as laser cladded tungsten carbide exhibit superior performance in drilling and excavation of the regolith, compared to similar hardened steel products. This study indicates the need for inclusion of wear-resistant technology in future studies on drilling and excavation tools and can lead to the development of more robust materials for use in future LSS.

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