

TESTING OF EXOMARS EM DRILL TOOL IN MARS ANALOGOUS MATERIALS

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ABSTRACT

In December 2009, a dedicated ESA Working Group on Mars Soil Characterization proposed a new reference set of lithologies to be used in the next test campaigns foreseen on the ExoMars Rover Drill Unit. The identified materials encompass: sandstones, claystone, gypsum of micro-crystalline type, geysirites (hydrothermal deposits), lava of basaltic and highly weathered types, stromatolites. The procurement of these materials has been completed in the timeframe June – November 2010.

Scope of this test activity is to extend the characterization of the Drill to a wider range of materials, to verify its performance and the limit of its capabilities on materials different from those used until now as a reference.

In particular, in this paper, the main outcomes relevant to the laboratory characterization of the collected materials and to the testing of the Exomars Drill Tool Engineering Model in laboratory conditions will be illustrated.

The testing of the Exomars drill tool Engineering Model in Mars like environmental conditions is scheduled to be completed by mid 2011.

1. INTRODUCTION ON EXOMARS DRILL UNIT

The ExoMars Drill and Sampling system is composed of three main elements: the Drill Unit, the Positioner Unit and the Electronics Unit. The Drill Unit and Positioner Unit are installed on the front panel of the ExoMars Rover as schematized in Fig. 1, showing the system in stowed configuration. The main part of the Electronic Unit is instead located inside the Rover main body, in the so called Analytical Laboratory Drawer (ALD), a thermally control unit which include also the scientific instruments and the mechanisms deputed to process and distribute the acquired sample. Once the EXM Rover is deployed and operate on the Mars surface, the Drill Unit can be deployed for its foreseen operations by means of a 2 d.o.f. Positioner as shown in

Fig. 2 for the drilling scenario and Fig. 3 for the sample discharge into the Sample Processing Facility.

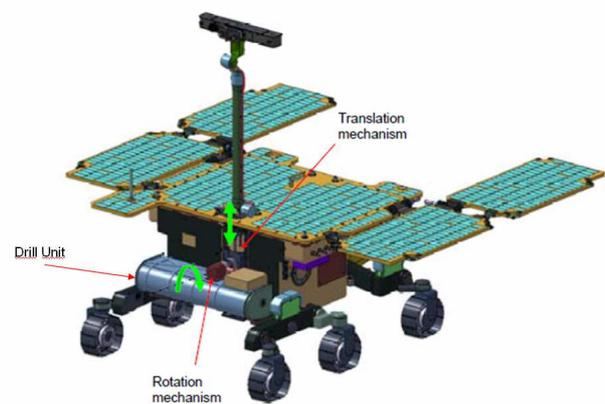


Fig. 1 ExoMars Rover with the Drill and Sampling System

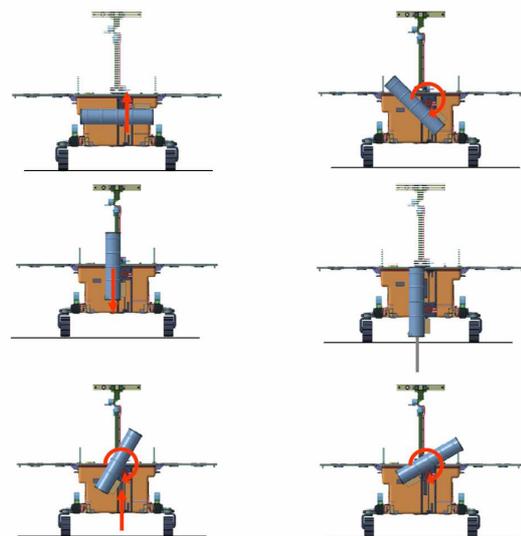


Fig. 2 Different phases of Drill operations: from stowed configuration to sample discharge

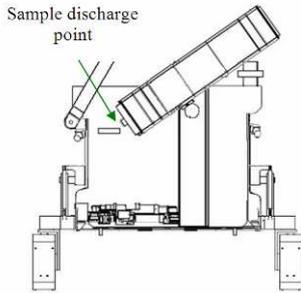


Fig. 3 Drill and Sampling System deployed for sample discharge

The Positioner consists of a linear translation mechanism and of a rotational joint, and include also a jettison device to be used in emergency. The Drill Unit main assemblies are: drill sliding carriage (rotating mandrel), drill translation group, rod magazine group, extension rods and drill tools. The drill tool contains the mechanisms for sample acquisition and discharge. All drill unit mechanisms and rods are placed in a light weight structure called drill box.

In Fig. 4 some basic elements of the developed H/W are shown: the integrated overall system, a portion of drill string, the forward part of the drill tool in drill mode and core mode.

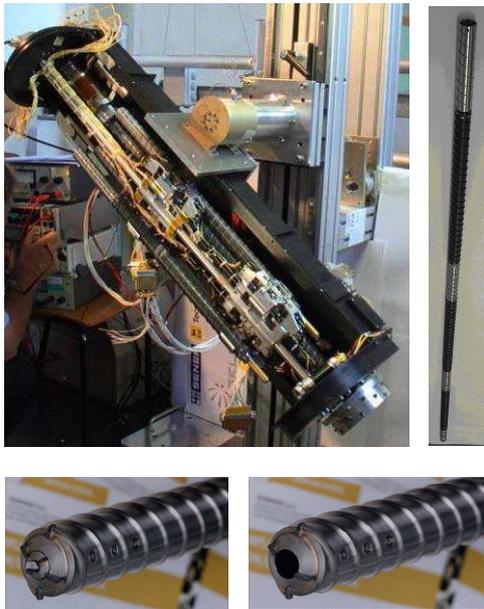


Fig. 4 Drill and Sampling System H/W – Breadboard Model

The drill system operates such that once the desired depth for sampling has been reached, the coring action is started and the sample is collected and “swallowed” in the front part of the tool by means of a dedicated mechanism. This mechanism, further to providing a

physical chamber where to keep the sample, avoids the loss of the sample during the recovery of the drill string. This mechanism is based on implementing a shuttering system which can occlude, to a selectable degree, the sample holding chamber itself. The level of utilization of such mechanism can be programmed based on characteristics observed during the different testing activities: most of the material do not need any shuttering action to be kept in place, others may need some partial containment.



Fig. 5 ExoMars Drill Tool EM during integration

A Drill Tool EM (with the spectrometer Ma_Miss optical parts integrated) has been manufactured. Fig. 5 shows the Drill tool and some of its internal mechanism during integration. The EM Tool has been tested in thermal environment to verify mechanism correct functioning in Mars like temperatures. Fig. 6 shows the Drill Tool EM placed in Thermal chamber for testing. Concerning Ma_Miss spectrometer, Fig. 7 provides some details on the optical observation window placed on the Drill Tool body.



Fig. 6 Overall set up used for the Drill Tool EM (inclusive of Ma_Miss optical parts) thermal testing



a) Lamp lit and the light conveyed via optical fibre and optical prism through the sapphire window (taken over a dark background)



b) Lamp switched off (taken in normal laboratory illumination conditions)

Fig. 7 Detail on the Ma_Miss optical observation window placed on the Drill Tool body

This EM Drill Tool has been used for the first test campaign on the collected Mars analogous material as described in the subsequent paragraphs.

2. LABORATORY CHARACTERIZATION OF THE MARS ANALOGOUS MATERIALS

In order to simulate Martian conditions also in terms of soil composition, a set of sample materials have been collected based on geological considerations. This set of materials includes:

Stromatolites: Precambrian stromatolites have been identified in Morocco South of Ouerzazate. The lithology consists of red limestone Precambrian in age being a good analogue of possible Martian stromatolites.

Sandstone High Quartz Content (HQC): this lithologies is collected in the Marnoso Arenacea Formation, a turbiditic unit with source in the Lombardian Alps.

Sandstone Low Quartz Content (LOC): This set of samples has been collected in the slabs of the Argille Scagliose of the Val Marecchia, a melange-like chaotic deposits with large units ranging from deep-sea fan to shelf deposits. The sample set is coming from the shallow-water tidal-dominated sandbodies poor in quartz and rich in limestone component.

Claystone High Calcium Content (HCC): the term “claystone” is a very general term that means cemented

clay. It has been decided to collect a particular kind of claystone called marls. These are clay with a percentage of calcareous material that hardens the rock. The first set of samples have been selected with relatively high (about 70%) content on calcium carbonate.

Claystone Low Calcium Content (LCC): this second marl lithotype has been selected from the same marl family, with a lower amount of calcium carbonate content, in order to have a “softer” material of the same geological unit.

Gypsum/Gypsarenaites: Samples are provided from the Vena del Gesso, the Messinian formation cropping out in Emilia Romagna.

Hydrothermal Deposits (Geyserites): This lithology has been included to investigate hydrothermal systems that are a possible astrobiological and geological target. The collected samples are from the Solfatara at Pozzuoli (Italy). This area is a sort of type area for the hydrothermal deposits being the first geological features recognised and studied as hydrothermal system.

Basaltic lava: Samples of lava flows are from Mount Etna (Sicily).

Strongly weathered lava: This lithology has been collected on the east slope of Mount Etna. The level of weathering has been kept to a medium-high value to have consolidate specimen.

In Fig. 8 sample of these materials are shown. All samples, except stromatolites, have been collected in Italy.



Fig. 8 Overview of collected materials

In order to test the ExoMars Drill capabilities in a controlled environment, these materials have been mechanically characterized; Geyserites has been excluded from the characterization campaign due to its very poor mechanical properties. In addition, also Marble and Red-Brick have been included in characterization campaign as “reference” materials (since these materials have been widely used in testing the ExoMars Drill).

The characteristics identified as relevant to drilling performances are the following:

- Compressive Strength
- Knoop Hardness
- Cerchar Abrasivity Index (CAI)

Compressive strength and Hardness strongly influence the performance of the drill in terms of cutting/advancing speed in the soil. Abrasivity index is, instead, an indication of the time needed to lower the performances of the cutting items. A brief description of the characterization tests procedure and execution is given in next sections.

2.1. Uniaxial compressive strength

The compressive strength of the materials has been evaluated by using prismatic samples with a nominal square cross section. The tests have been performed by using the MTS 810 Static Test System, with a maximum applicable load of 250 kN. The test setup is shown in Fig. 9.

The load applied during the test has been recorded by a load cell housed in the upper cross head of the system, above the fixed cylinder. All tests have been conducted in a displacement controlled mode at a cross head speed of 1.5 mm/min. The applied displacement has been recorded by means of an LVDT integrated in the MTS static test system. Displacement and load signals have been acquired at a sampling frequency of 20 Hz. The recorded data also include high speed movies of all the tests at a sampling rate of 1200 frame per seconds. The acquisition of the applied load and of the displacement allowed the evaluation of an engineering stress vs. nominal strain curve. The nominal strain is actually a rough estimation of the real strain in the rock specimen, as it is simply obtained by dividing the displacement by the height of the sample. For all the materials, an Engineering Stress vs Nominal Strain curve has been identified. An example referred to the Claystone HCC is shown in Fig. 10. In these curves a marked non-linear initial phase can be detected for all the rock samples. A tangential modulus has been evaluated by means of a linear regression in the middle of the stress vs. strain response, where curves present a almost linear behaviour.

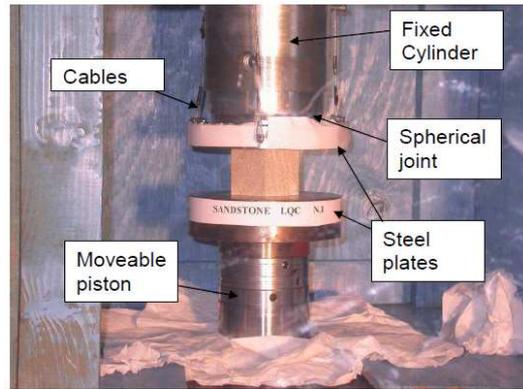


Fig. 9 Set up used for Uniaxial Compressive Test

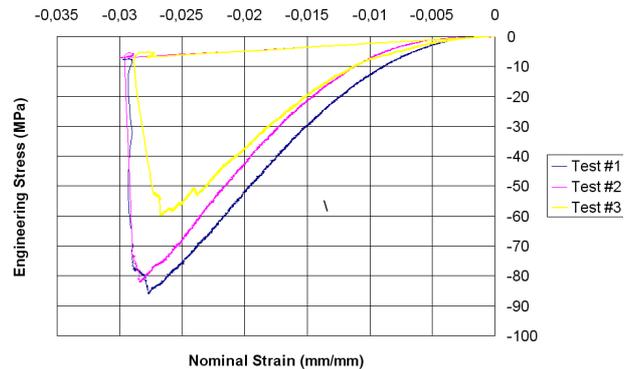


Fig. 10 Example of recorded stress-strain curves (Claystone HCC)

The ultimate compressive strength of each material is identified with the point in which the sample completely loses its mechanical resistance. In this condition, the sample is failed and, for each material, the failure mode has been recorded. An example is given in Fig. 11.

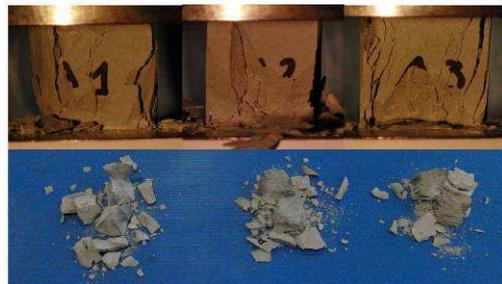


Fig. 11 Example sample shape after test (Claystone HCC)

Fig. 12 summarizes the results of the compressive strength characterization campaign. Materials are in order of increasing ultimate compressive strength values.

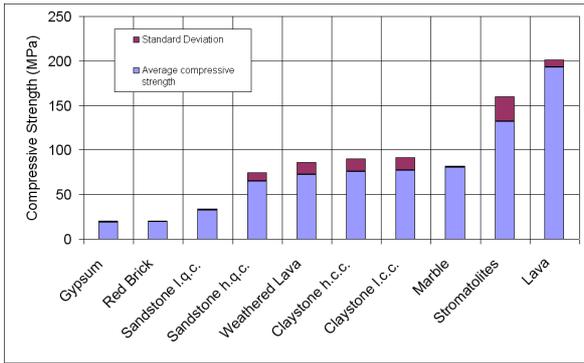


Fig. 12 Summary of UCS test results

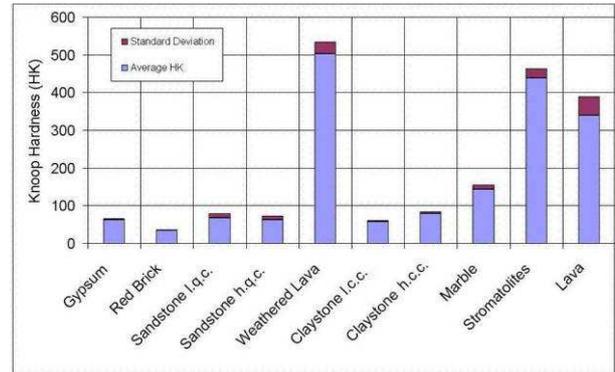


Fig. 14 Summary of Knoop micro hardness test results

2.2. Knoop micro hardness

The hardness of the mars-like materials and of the two reference materials have been characterised by means of Knoop hardness tests. This test, conducted in the micro range of force (1 to 1000 gf) according to the procedure prescribed by ASTM Standard E-384-10e2, is typical in geomechanical applications. The Knoop test adopts a rhombic-based pyramidal shaped diamond indenter, which is shown in Fig. 13. The Knoop hardness number is obtained by dividing the force applied to the indenter by the projected area of permanent indentation. The indentation is rhombic shaped and is characterised by the length of the diagonals that are dissimilar, as shown in Fig. 13.

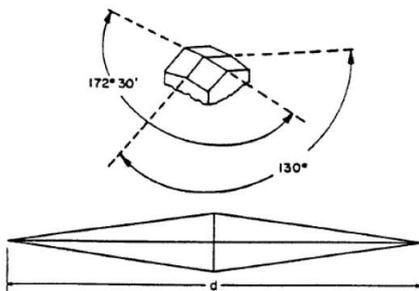


Fig. 13 Micro indenter for Knoop micro hardness test

Fig. 14 shows a summary of the Knoop micro-Hardness tests results. The hardest material is the Weathered Lava, followed by Stromatolites and Basaltic Lava. Other materials are all in the same range of hardness (50-100 HK), excluding Marble which is slightly harder.

2.3. Cerchar Abrasivity Index

The abrasivity of the mars-like materials and of the two reference materials has been measured by means of the Cerchar test, which is a simple and widely diffused method to assess rock abrasiveness.

The Cerchar test consists in scratching the surface of a rock by means of a sharp-pin of heat treated alloy steel, which is called “stylus”. Details on the Cerchar test apparatus and the stylus are given in Fig. 15 and Fig. 16.

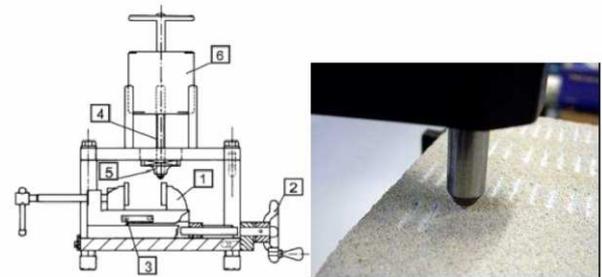


Fig. 15 Schematics of apparatus for Cerchar abrasivity test



Fig. 16 Some details on indenter used in Cerchar abrasivity test

The Cerchar Abrasivity Index is correlated to the average diameter of the abraded tip after scratching. The resulting classification is detailed in Fig. 17.

CAI value	Category (after CERCHAR, 1986)
0.3 – 0.5	Not very abrasive
0.5 – 1.0	Slightly abrasive
1.0 – 2.0	Medium abrasive to Abrasive
2.0 – 4.0	Very abrasive
4.0 – 6.0	Extremely abrasive
6.0 – 7.0	Quartzitic

Fig. 17 Abrasivity classification according to Cerchar method

Two examples of microscopic pictures taken on the stylus to determine the CAI are shown in Fig. 18 and Fig. 19, showing the effect of the scratching in case of low abrasive material (Fig. 18) and in case of high abrasive material (Fig. 19).



Fig. 18 Example of indenter wearing in case of low abrasive material (Gypsum)



Fig. 19 Example of indenter wearing in case of high abrasive material (Strongly Weathered Lava)

Summary of the CAI test results are reported in Fig. 20.

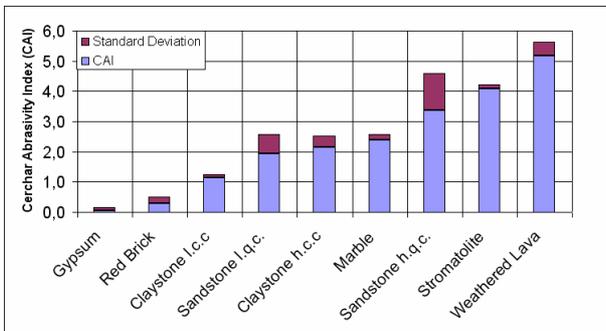


Fig. 20 Summary of Cerchar abrasivity test results

2.4. Overall considerations on materials

It can be observed that the gypsum and the red brick, which present the lowest compressive strengths, are also characterised by low values of hardness. At the same times, Stromatolites and Basaltic lava, which have high values of compressive strength, also present significantly high values of hardness. The marble, which ranks third for compressive strength, obtains the fourth values of micro hardness. However for some materials strength and hardness levels seem quite unrelated. Such materials are the two types of claystones, which exhibit medium values of compressive strength but very low HK levels, and, most of all, the Weathered Lava. The peculiar porous structure of such type of lava leads to a medium level of compressive strength, which is a macroscopic property influenced by the presence of voids. The material, however, presents very high mechanical properties at the microscale level, as it is indicated by the extremely high value of HK hardness.

Moreover hardness and CAI values seem strictly related for all the material.

Stromatolites and Basaltic Lava possess mechanical characteristics that are beyond the ExoMars Drill capability (especially in terms of compressive strength). In particular, the Lava has been excluded by this test campaign because preliminary testing showed that the Drill is not effective in such tough material. Stromatolites also exhibit very high mechanical properties but drilling tests (as described in next sections) have been executed to test the Drill performance also on very strong materials.

The results of the mechanical characterization of these rocks indicate that that this set of materials is very effective to the purpose of the ExoMars Drill mechanical testing. In facts, it includes materials in a wide spectrum of mechanical properties, starting from “loose” and very low abrasive materials up to very tough and abrasive materials.

3. DRILLING AND CORING TESTS IN THE MARS ANALOGOUS MATERIALS

The test campaign carried out utilizing this new set of materials was aimed at verifying the capabilities of the Drill both in terms of collecting samples and in terms of drilling performances.

In particular, the test campaign was composed of two different types of tests: drilling test and coring (sampling) tests, as described in subsequent sections.

3.1. Drilling Tests

The execution of the drilling tests was conducted utilizing different levels of vertical thrust in order to verify the penetration ratio, the cutting capabilities of the drill bits and the generated torque on the tool for each material. Rotation speed of the drill mandrel is constant in all cases (60 rpm). The test execution was conducted, material by material, starting the drilling operation with a vertical thrust of 250 N which is kept constant for a fixed amount of time. At the end of this period, the penetration inside the material is measured (in order to obtain the mean advancing speed) and the thrust increased to 350N. The thrust is then kept constant for the same amount of time. At the end the delta-penetration is measured in order to obtain the mean advancing speed at this thrust level. Afterward, the thrust is once more increased up to 450N. The delta-penetration occurred after the same amount of time is recorded to obtain the advancing speed. At this stage, the drill is stopped and retracted. The sequence is repeated in each material.

This procedure allows to plot, for each material, an “Advancing Speed vs Thrust” curve, which is very interesting both in terms of drilling performances and in terms of mission timelines planning. Of course, these curves are only references for the drilling performances because other factors may influence it, for example the wearing of the drill bits.

Fig. 21, Fig. 22 and Fig. 23 shows the curves for, respectively, easily, intermediate and hardly drillable materials. All the materials exhibit a non-linear relation between applied thrust and advancing speed.

For the easily and intermediate drillable materials, the resulting advancing speed is in line with the requirements placed by the mission timelines. Moreover, advancing speeds are similar to the speeds expected based on the experience gained by SG in previous test campaigns (drilling Marble, Red Brick, Tuff, etc.).

For the hardly drillable materials, Stromatolites and S.W. Lava, the resulting advancing speed is very low. This was predictable for Stromatolites due to its very high compressive strength. Regarding S.W. Lava, the considerations regarding the difference between the microscopic structure (Knoop hardness) of the material and the macroscopic behaviour (compressive strength) were confirmed by the test results: the material is very tough at microscopic level, which is the level involved in the drilling. On the contrary, its macroscopic characteristic is lower because of the presence of “voids” inside the material itself.

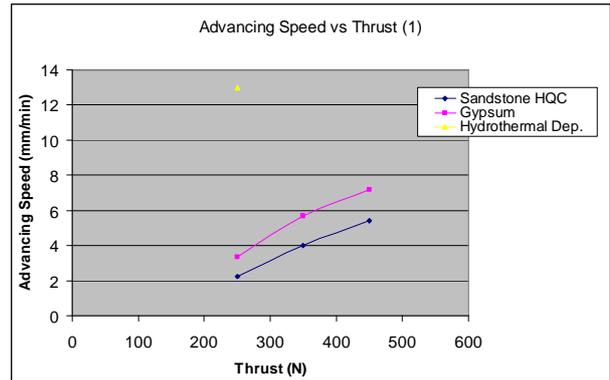


Fig. 21 Speed thrust results for a group of materials of “easy” drillability

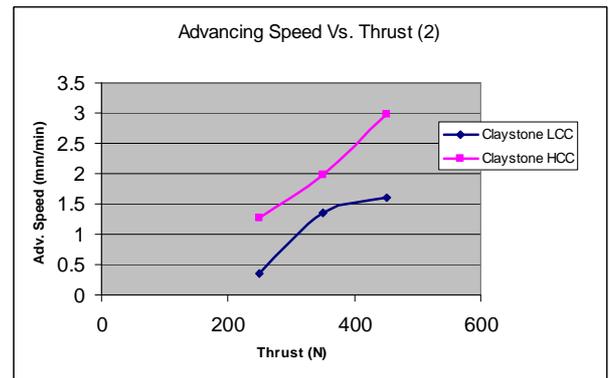


Fig. 22 Speed thrust relation for a group of materials of “intermediate” drillability

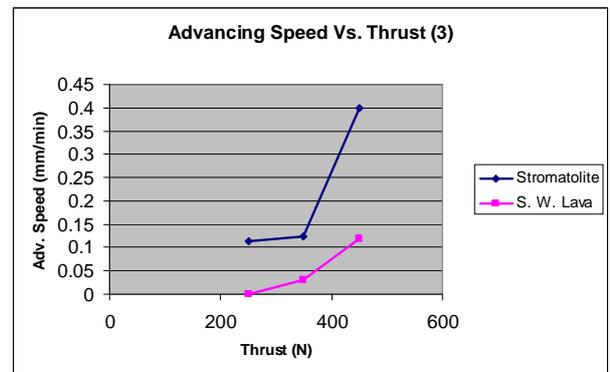


Fig. 23 Speed thrust for a group of materials of “hard” drillability

3.2. Sampling Tests

Sampling tests were also conducted on each of the drillable materials (easy and intermediate drillability). Five samples of each material have been collected and discharged by the Drill Tool sampling mechanism.

Fig. 24, Fig. 25 and Fig. 26 show, respectively, examples of sample of sandstones (HQC and LQC), claystones (HCC and LCC), Geyselite and Gypsum. Fig. 27, instead, shows the Drill Tool during the

discharge of a Claystone HCC sample.

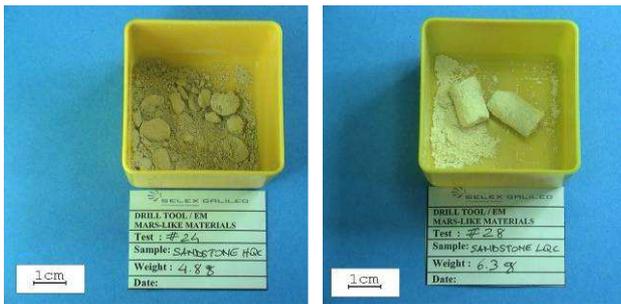


Fig. 24 Example of collected samples: sandstones.



Fig. 25 Example of collected samples: claystones.



Fig. 26 Example of collected sample: hydrothermal deposits (geyserite) and gypsum



Fig. 27 Drill Tool EM during a Claystone HCC sample discharge

For all the samples the quantity of material is satisfactory and always in line with the requirements of the mission. Moreover, in most cases, the sample is

solid (“carrot” type), meaning that the alteration of the sample resulting from the interaction with the Drill Tool is low, and the possible corruption and contamination of the original material is minimal. This is important to allow the preservation of the possible volatile and organic fractions inside the sample. No significant amount of material has ever been lost during the sample recover operation.

The most difficult material to eject was found to be the Gypsum: despite its low mechanical properties, this material tends to “stick” against the walls of the sampling chamber, requiring a higher value of force from the Drill Tool piston (measured by acquiring the current demand to the piston motor).

4. CONCLUSIONS AND FUTURE ACTIVITIES

The ExoMars drill and sampling system has so far been tested in a variety of conditions, including laboratory tests in Mars-analogous materials (as proposed by a dedicated ESA Working Group on Mars Soil Characterization).

The achieved results are in line with the expected drill overall performances in terms of key issues, such as: thrust, torques, operational timelines and amount of sample material collected and discharged.

These tests on the Mars-analogous materials have been so far performed in laboratory conditions. Further testing in Mars-like environment (in terms of temperature range, pressure, CO₂ atmosphere) are about to start and will be completed by June this year.

The overall results so far achieved confirm the effectiveness of the drill and sampling approach followed for the ExoMars Drill.