# The mechanical response of Etnean volcanic sand and rocks to impact loading and the effect of sand impingement on titanium alloys

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Volcanic sand is a granular material generated by the interaction between magma, water and air during volcanic explosion. Once the magmatic material reaches the Earth surface, it is subjected to rapid cooling process and to an increase of viscosity and reduction of fluidity caused by the emission of gases and vapor. Because of its viscosity and the fast cooling, the minerals present in the magmatic material cannot arrange themselves in an organized structure producing partially or completely vitreous rocks, shards and beads.
Etnean Volcanic ashes are mainly composed of two minerals: cristobalite and anaorthite. The former is characterized by the same chemical composition of silica (SiO2) but distinct crystal structure, the latter ($CaAl_2Si_2O_8$) is omnipresent in all rocks of mount Etna [3, 4, 5]. The Etna rocks investigated in this study are intermediate alkali basalts collected from the south-east flank of the volcano.

A reliable characterization of the mechanical behavior of volcanic rock and sand is paramount for the interpretation of large-scale geophysical deformation data. Moreover, Etnean sand and rocks are widely used as construction materials [6, 7]. Mechanical properties such as compressive uniaxial strength and brittleness of volcanic materials also provide information on its percussive and rotary drillability and consequent on the wear and tear of drilling tools [1, 2].
Ash clouds from eruptions are regarded by international aviation agencies as a dangerous environment for aircraft engines and an immediate safety concern [13]. The abrasiveness of sands varies depending on particle size, shape, angularity and friability of the grains [8, 11]. Volcanic sand is about four times more erosive then quartz sand [12]. The ingestion of volcanic particulate affects the performance, reliability and durability of gas turbine engines. Its impingement and deposition on blades and vanes cause, among other effects, the erosion of stator and rotors surfaces, modifying their profiles. This causes a loss in power, the reduction of the engine efficiency and of its operating life [9, 10].

An experimental campaign was undertaken in order to characterise the response of Etnean volcanic sand and rocks at quasi-static and high rate of strain. Etna basalt cubic compression specimens approximately 4 mm long of Etna basalt were machined out of the parent rock material. The volcanic sand was collected from the South-East flank of the volcano during the paroxysm of the 14th-16th December 2013. The granular material was separated from impurities and sieved to obtain an approximately homogeneous size distribution of grains, representative of the average dimensions of the volcanic debris that reaches the neighboring airport and cities during the eruptive activity. The distribution of particle size was evaluated using contrast edge detection techniques on binary images. The microstructure of the volcanic sand grains was examined by means of a Carl Zeiss Evo LS15 VP- Environmental Scanning Electron Microscope. Volcanic ash samples of mass correspondent to the representative volume element were weighted by means of a precision scale and subsequently compacted using a specimen filling procedure established to obtain experimentally fixed and reproducible void ratios. The final sand samples had a diameter of 20 mm and lengths between 6 and 8 mm corresponding to distinct void ratios. The dimensions of the granular material samples were defined to be a good trade-off between the minimization of the containment boundary effects and the obtainment of dynamic equilibrium during high strain rate compression tests.

In order to assess the abrasiveness of the volcanic sand upon components of aerospace strauctures made of titanium alloys and evaluate its mechanical response when subjected to high strain rate loading, uniaxial compression tests were carried out by means of a screw-driven testing machine and a long split Hopkinson bar provided with a 2.7 m long striker. Two types of sand containments were designed in order to characterize the volcanic particulate under uniaxial strain and uniaxial stress loading conditions. A titanium alloy cylindrical containment was used to reproduce uniaxial strain loading conditions whilst a deformable latex containment was used to reproduce uniaxial stress conditions (Fig. 1).
During high rate compression experiments the load was transmitted from the input bar to the sample and from the sample to the output bar by means of two titanium alloy anvils. These were machined using the same titanium alloy with same cross section geometry of the bars for a perfect mechanical impedance matching. These anvils were replaced after every test and their surface, eroded by the impingement of volcanic particulate examined using a Alicona Infinite Focus 3D Profilometer. A series of additional tests was conducted adopting anvils of different geometries for the sake of evaluating the effect of the impact angle on the erosion mechanism.

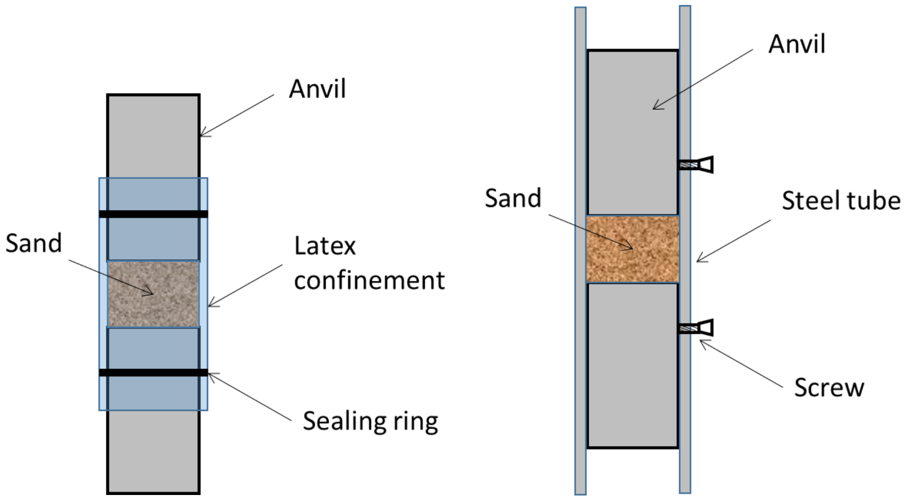

**Fig. 1: Latex (left) and rigid (right) confinement**

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