

DEFINING THE GEOTECHNICAL PROPERTIES OF LUNAR SIMULANT REGOLITH

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INTRODUCTION

Future lunar missions demand understanding regolith behaviour to support infrastructure. Although Apollo returned real regolith, its scarcity prevents bulk destructive testing. Terrestrial simulants enable large-scale experiments instead. This study examines Hostun sand for comparison and Exolith Lab's high-fidelity analogues to assess their geotechnical properties for lunar applications.

HOW DID THE MOON FORM AND WHAT IS THE SURFACE LIKE?

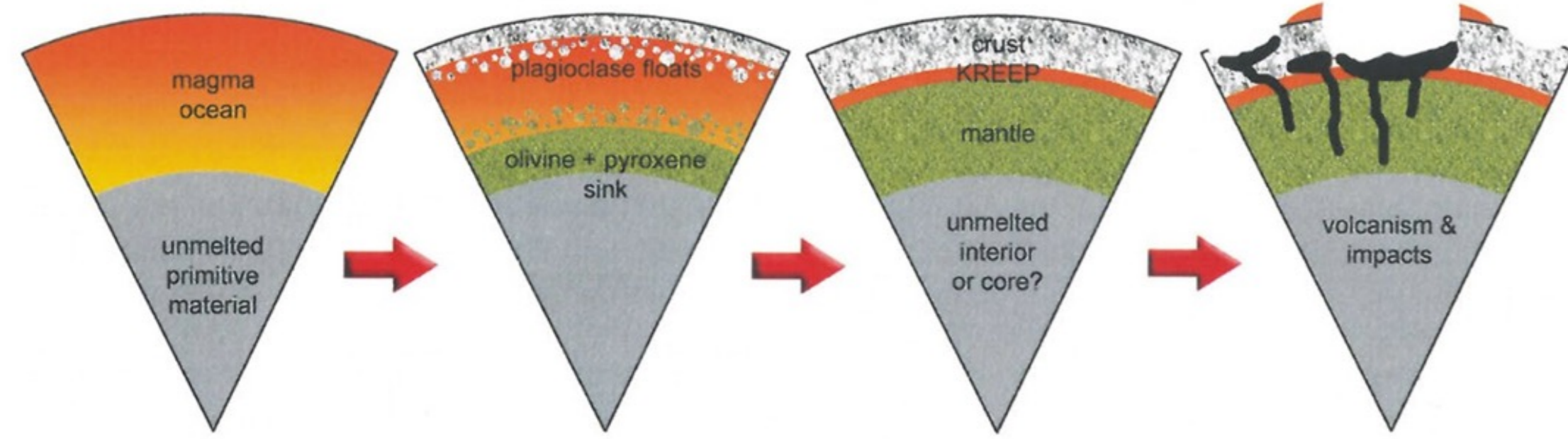


Figure 1. Diagram illustrating the timeline of the lunar magma ocean hypothesis leading to the distribution of basalt and anorthosite crust across the surface (NASA, 2024)

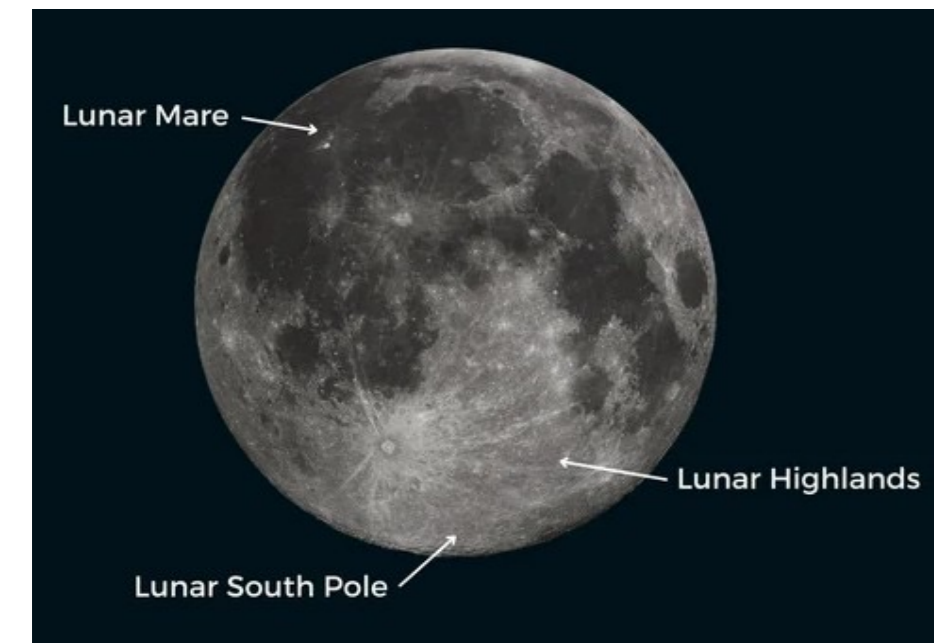


Figure 2. Illustration depicting examples of lunar regions used for simulant type separation (Exolith labs, 2024)

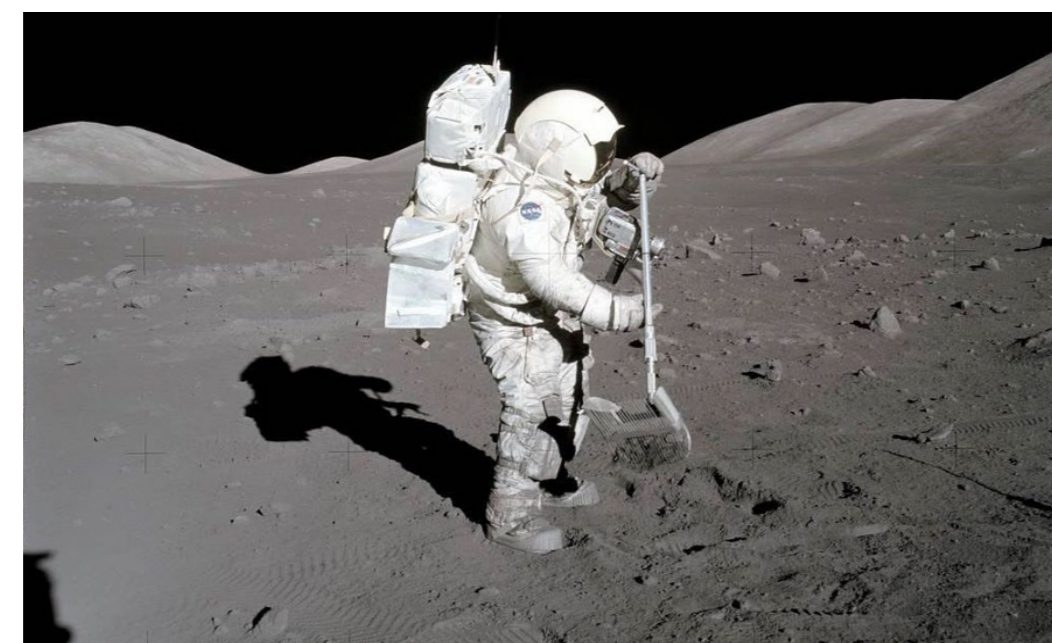


Figure 3. Photo from Apollo 17 shows an astronaut collecting a sample of lunar regolith. The terrain appears silty with scattered boulders (NASA, 2024)

The lunar regolith is a fine, unconsolidated layer formed by micrometeoroid impacts and thermal processes. It occurs as basaltic regolith in maria, feldspathic regolith in highlands, and anorthositic regolith at the south pole, differentiated by colour and age.

WHAT IS THE LUNAR SURFACE MADE OF AND HOW IS IT SIMULATED?

Sample type	Image
LHS highland simulant	
LHS-25A highland agglutinated simulant	
LMS mare simulant	
LSP south pole simulant	
Hostun sand	

Labels: BASALT, ANORTHOSITE, PYROXENE, HOSTUN

Table 1. Contains simulant type and its visual appearance with 10mm cube
The lunar surface is predominantly made up of 5 minerals in varying percentages depending on the region: Basalt, Anorthosite, Pyroxene, Ilmenite and Olivine. Based on data collected from the returned lunar samples, simulants can replicate the average mineral distribution by region as well as particle size distribution to varying accuracy.

WHAT EQUIPMENT WILL I BE USING FOR MY TESTS?



Figure 4. (left) Whole setup of loading frame, (right) particle in between the two platens.

Figure 5. (left) Morphologi machine, (Right) Keyence microscope

Figure 6. Interparticle apparatus

Above are the 4 main pieces of equipment used in my project. From Left to right: uniaxial loading machine, used to crush individual particles and define Weibull modulus, characteristic strength, peak stress and Hertz models. Morphologi machine, used to define many particle shape and surface characteristics such as particle size distribution, roundness, CE diameter, aspect ratio and circularity. Keyence microscope, used for optical and surface analysis such as sq roughness and feret diameters. Interparticle apparatus, performs normal and tangential loading on two particles in contact and can experiment with cyclic loading as well as further verify uniaxial data.

UNIAXIAL LOAD TEST – HERTZ MODEL, PROBABILITY OF SURVIVAL, CHARACTERISTIC STRENGTH AND WEIBULL MODULI

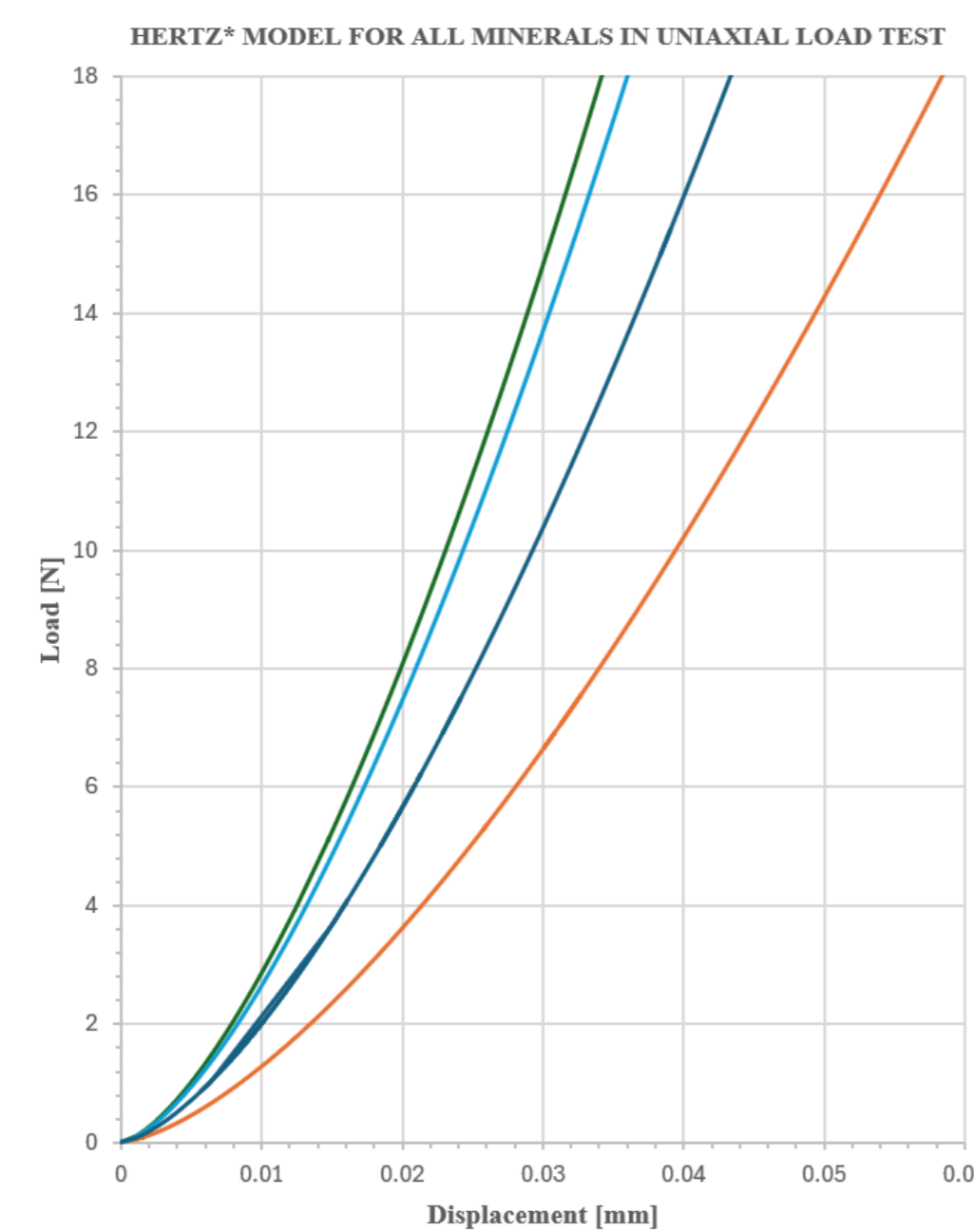


Figure 7. Hertz* model for all minerals tested, accounting for roughness

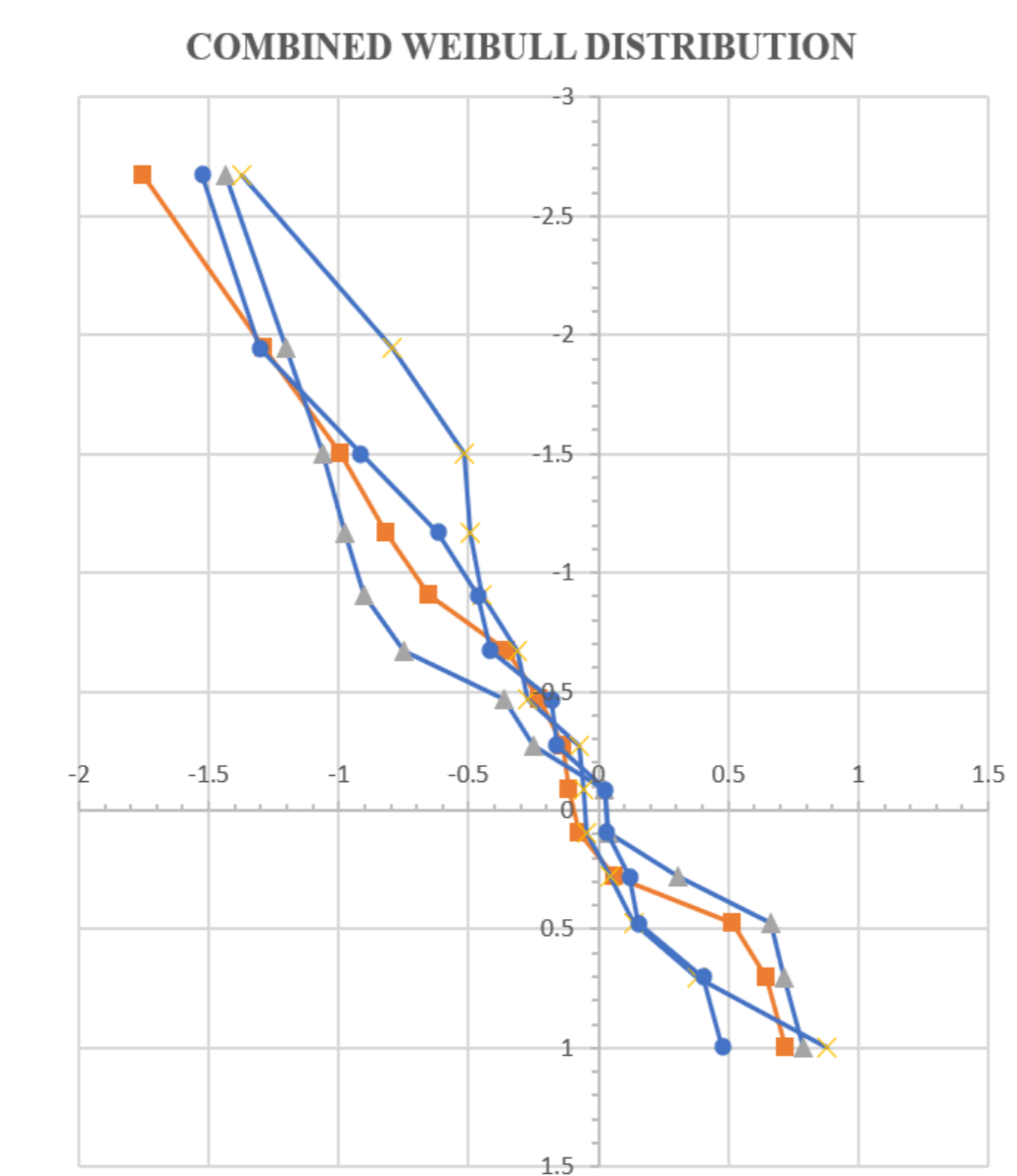


Figure 8. Combined Weibull moduli graphs for all minerals tested

Figures 7-9 are the graphs produced using data from the uniaxial loading machine and the Keyence microscope. Starting with figure 7, this graph includes all of the Hertz Models with roughness of the 4 constituent minerals that made up the simulants. Due to the high roughness of the particles the initial models without roughness made predictions too far from the experimental data. There is a clear difference in stiffness between the different minerals, with basalt predicting softer behavior. All particles only displace by a small amount and a small load however this is not of a concern due to the small particles sizes of 0.5mm. Figure 8 compared all Weibull moduli graphs for the minerals. Noticeably all minerals predict a low Weibull modulus (between 1 and 2) indicating low predictability for fracture load. Finally, figure 9 compared all probability of survival graphs for a given stress. Hostun quartz is noticeable higher than the 3 minerals in the Exolith simulants, indicating it breaks at much larger stress levels on average, and therefore would perform very differently under high stress than the Exolith simulants

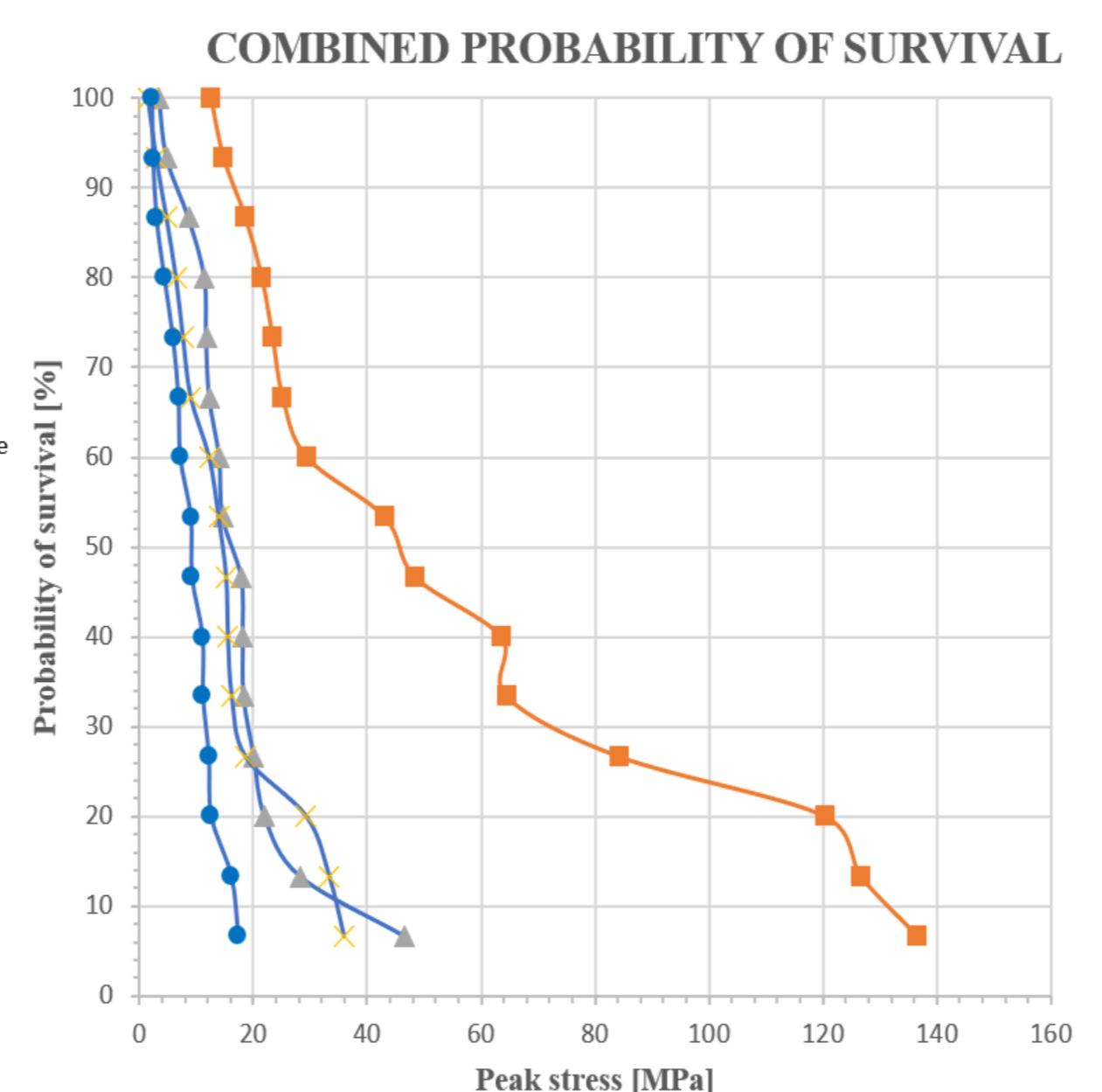


Figure 9. Combined probability of survival for a particle for all minerals tested

MORPHOLOGI TESTING – PARTICLE CHARACTERISTICS

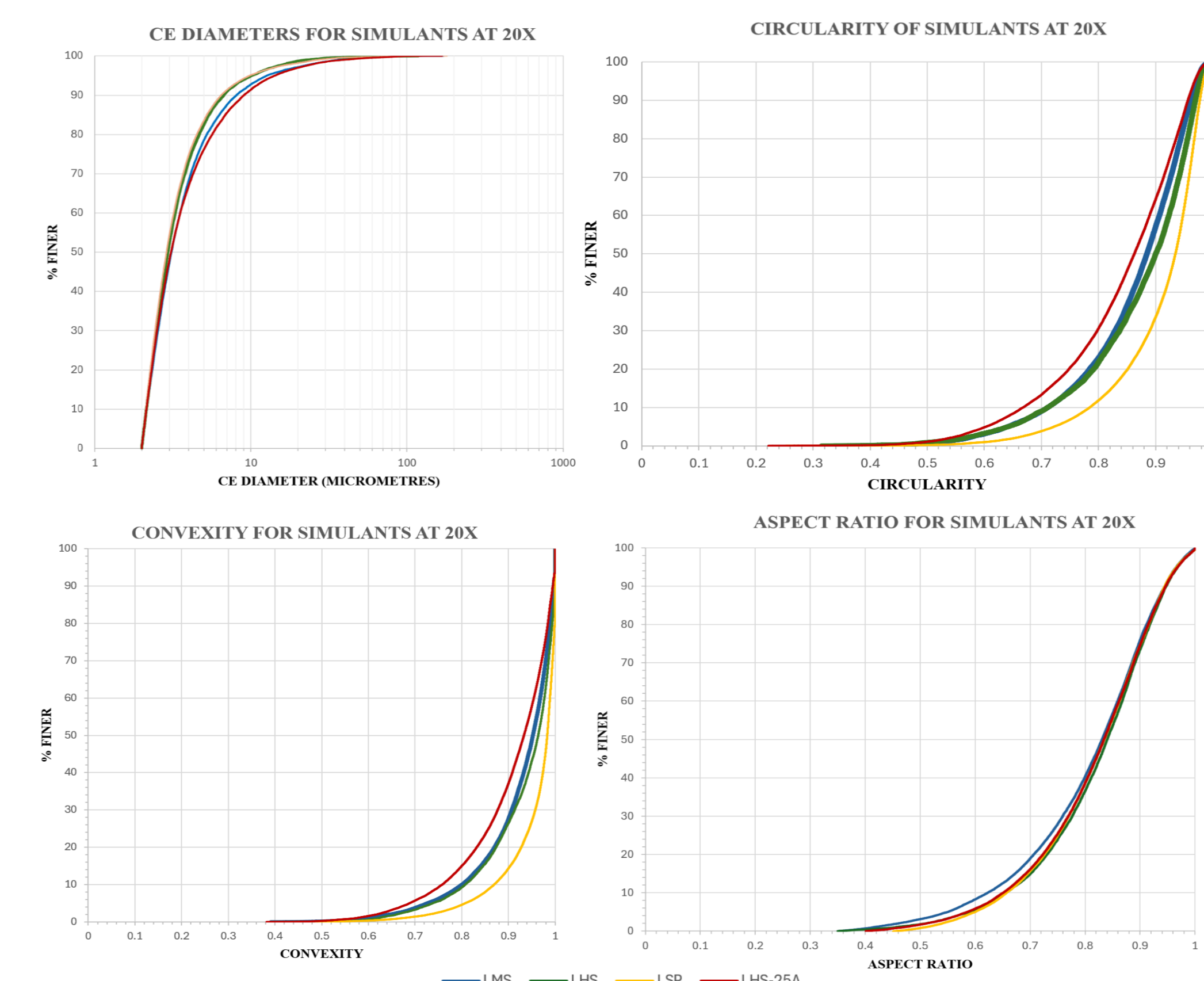


Figure 10. Particle shape and topography descriptors for regolith categories

Particle shape characteristic tests were carried out at 10x and 20x magnifications however it was found that 10x was not high enough of a resolution to make accurate readings, therefore only 20x has been included. Unfortunately, the 50x lens and the Hostun sample could not be scanned at 20x due to a system error so only Exolith data is available at 20x as of current. Additionally, some parameters can be more accurately produced than others due to a minimum pixel size requirement. For example, convexity requires higher pixel areas and so data under that requirement cannot be validly used. Additionally, due to the magnification restrictions, the CE diameter graph abruptly stops rather than tailing off, which would be improved by higher magnifications.

INTERPARTICLE TESTING – CYCLIC LOADING AND MIXED MINERAL INTERACTIONS

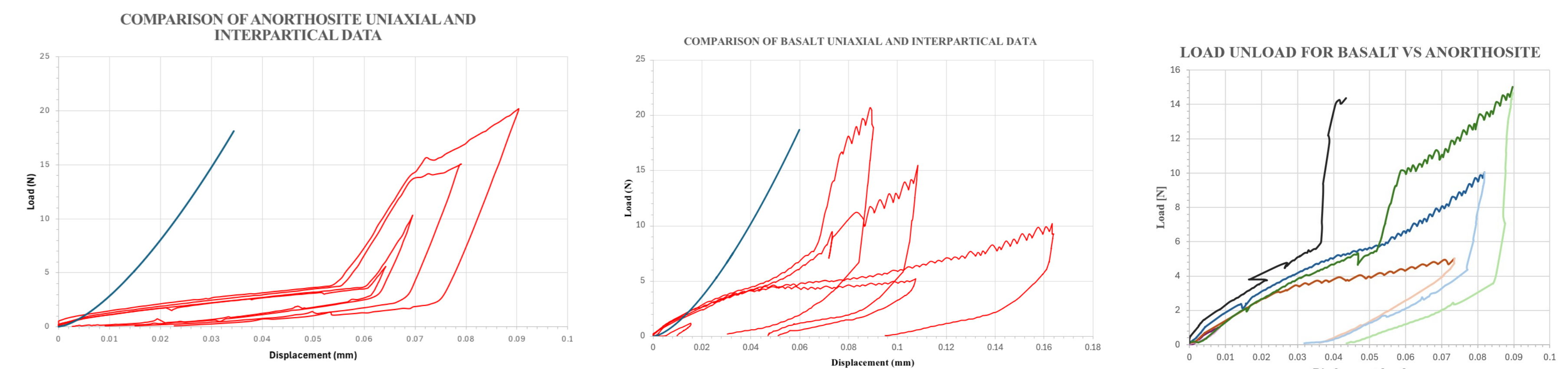


Figure 10. Cyclic loading graphs for (Left) Anorthosite vs Anorthosite, (middle) Basalt vs Basalt (Right) Basalt vs Anorthosite

During interparticle testing, 3 types of contacting pairs for tested due to size requirement of the apparatus. From left to right in figure 10, Anorthosite vs Anorthosite (also seen in figure 11), Basalt vs Basalt and Basalt vs Anorthosite. Unfortunately the tangential loading component was not operable at this stage and so only normal cyclic loading was carried out. For same mineral interactions (left and middle of figure 10), the hertz* graphs can also be plotted for comparison. Results vary quite vastly between uniaxial and interparticle, potentially due to a mechanical error with the machines which require further investigation

CONCLUSIONS

In conclusion, preliminary results for the properties of the simulants have been defined, however further work is clear to further validate the results, such as the need for a 50x magnification for Morphologi data. Physical properties such as Weibull moduli have been defined for the main component minerals, allowing for initial modelling accuracy for applications such as DEM, however further testing should be conducted to raise the number of tests per minimal to 30 to test repeatability and patterns, as well as broaden the testing to Olivine and Ilmenite, in addition to other simulants. For the particle shape and surface characteristics, initial findings are promising and highlight potential need for updating existing data on the true regolith within the NASA guide. Although the interparticle testing was not as successful as hoped, it has allowed for some identification of inherent issues within the machine itself, prompting further investigation to determine the source of errors affecting the data and mitigate impact on subsequent experiments.

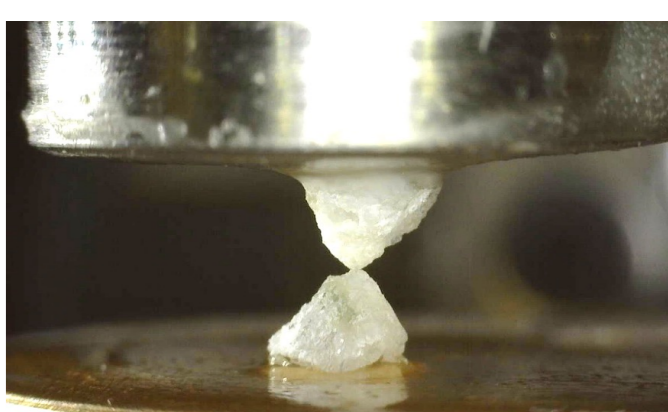


Figure 11. Image of interparticle apparatus containing two anorthosite particles with their peaks in contact