HYPERVELOCITY IMPACT TESTING OF MATERIALS FOR ADDITIVE CONSTRUCTION: APPLICATIONS ON EARTH, THE MOON, AND MARS

Erick Ordonez[1], Jennifer Edmunson[2], Michael Fiske[2], Eric Christiansen[3], Josh Miller[4],
Bruce (Alan) Davis[5], Jon Read[5], Mallory Johnston[1], and John Fikes[1]

[1]National Aeronautics and Space Administration George C. Marshall Space Flight Center,
Huntsville AL 35812, USA, Erick.A.Ordonez@nasa.gov (+1.256.544.6811)
[2]Jacobs Technology Inc., 1500 Perimeter Parkway, 4th Floor, Huntsville AL 35806, USA,
Jennifer.E.Edmunson@nasa.gov
[3]National Aeronautics and Space Administration Lyndon B. Johnson Space Center, 2101 East
NASA Parkway, Houston TX 77058, Eric.L.Christiansen@nasa.gov
[4]University of Texas at El Paso, 500 West University Avenue, El Paso TX 79968,
Joshua.E.Miller@nasa.gov
[5]Jacobs Technology Inc., 2224 Bay Area Boulevard, Houston TX 77058,
Bruce.Davis-1@nasa.gov

ABSTRACT

Introduction

Additive Construction is the process of building infrastructure such as habitats, garages, roads, berms, etcetera layer by layer (3D printing). The National Aeronautics and Space Administration (NASA) and the United States Army Corps of Engineers (USACE) are pursuing additive construction to build structures using resources available in-situ. Using materials available in-situ reduces the cost of planetary missions and operations in theater. The NASA team is investigating multiple binders that can be produced on planetary surfaces, including the magnesium oxide-based Sorel cement; the components required to make Ordinary Portland Cement (OPC), the common cement used on Earth, have been found on Mars. The availability of OPC-based concrete on Earth drove the USACE to pursue additive construction for base housing and barriers for military operations. Planetary and military base structures must be capable of resisting micrometeoroid impacts with velocities ranging from 11 to 72km/s for particle sizes 200μm or more (depending on protection requirements) [1, 2] as well as bullets and shrapnel with a velocity of 1.036km/s with projectiles 5.66mm diameter and 57.40mm in length [3], respectively.

Scope of Work

Three test articles were cast (15.24cm square by 2.54cm thick); one was layered and cut to size (15.24cm square by 5.72cm thick). Regolith simulants used were martian JSC Mars-1A, with a grain size of ≤5mm, and lunar JSC-1A with a grain size of ≤1mm. Test Article 1 contained JSC Mars-1A, OPC, and stucco mix (a mixture of sand, OPC, and calcined gypsum). Test Article 2, the additively constructed (layered) specimen, contained JSC Mars-1A, OPC, stucco mix, and Navitas 33 (a rheology control). Test Article 3 contained JSC Mars-1A, Sorel cement, and boric acid (a set retardant). Test Article 4 contained JSC-1A, OPC, and stucco mix. Test Articles are pictured in Figure 1.

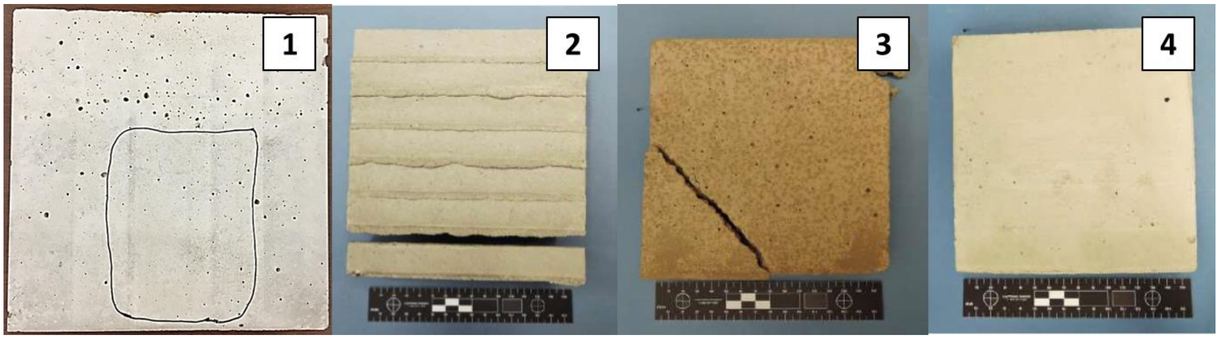

Figure 1: Test Articles. Note Test Article 2 layer broke off during shipping. Test Article 3 was also damaged during shipping. See text for a description of composition.

The selected impactor was a 2.0mm aluminum 2017-T4 (density of 2.796g/cm^3) sphere, known to provide target accuracy and consistent, comparable results. The density of the impactor is greater than micrometeorites (1-2g/cm^3 [4]) and less than ammunition (8.96g/cm^3 for copper and 11.35g/cm^3 for lead). All impact angles were 0 degrees. A velocity of 7.00±0.2km/s was chosen to represent the approximate mean expected velocity of micrometeorites on the surface of Mars [1], and a higher than expected velocity for bullets and shrapnel on Earth [5, 6]. Failure of the material was considered to be perforation, although spallation of the material is undesired as it could perforate critical interior structures or injure troops taking cover behind the structure.

Samples were prepared at Marshall Space Flight Center. Testing coordination and damage metrology was completed by the Johnson Space Center Hypervelocity Impact Technology Group. Testing took place at the White Sands Test Facility Remote Hypervelocity Test Laboratory in Las Cruces, New Mexico.

Findings

Figure 2 shows images of the impact craters. The impacts resulted in broken simulant grains, apparent in all samples. All witness plates, 0.102cm thick, and residing 10.16cm behind each sample, were not damaged. The impact on Test Article 1 resulted in a crater of 29.80mm x 27.10mm with a maximum depth of 10.30mm. No damage was apparent on the back side. Due to impact, layered Test Article 2 delaminated between layers printed on separate days instead of layers printed on the same day. The crater was 22.45mm x 32.78mm x 8.33mm depth. Test Article 3 (Sorel cement) had a crater 41.26mm x 41.34mm x 10.12mm maximum depth. Test Article 3 cracked and spalled on the rear side; the spall was 64.99mm x 52.04mm and a maximum depth of 9.96mm. Test Article 4 testing resulted in a crater 25.60mm x 25.85mm x 6.48mm deep, with not damage apparent on the back side.

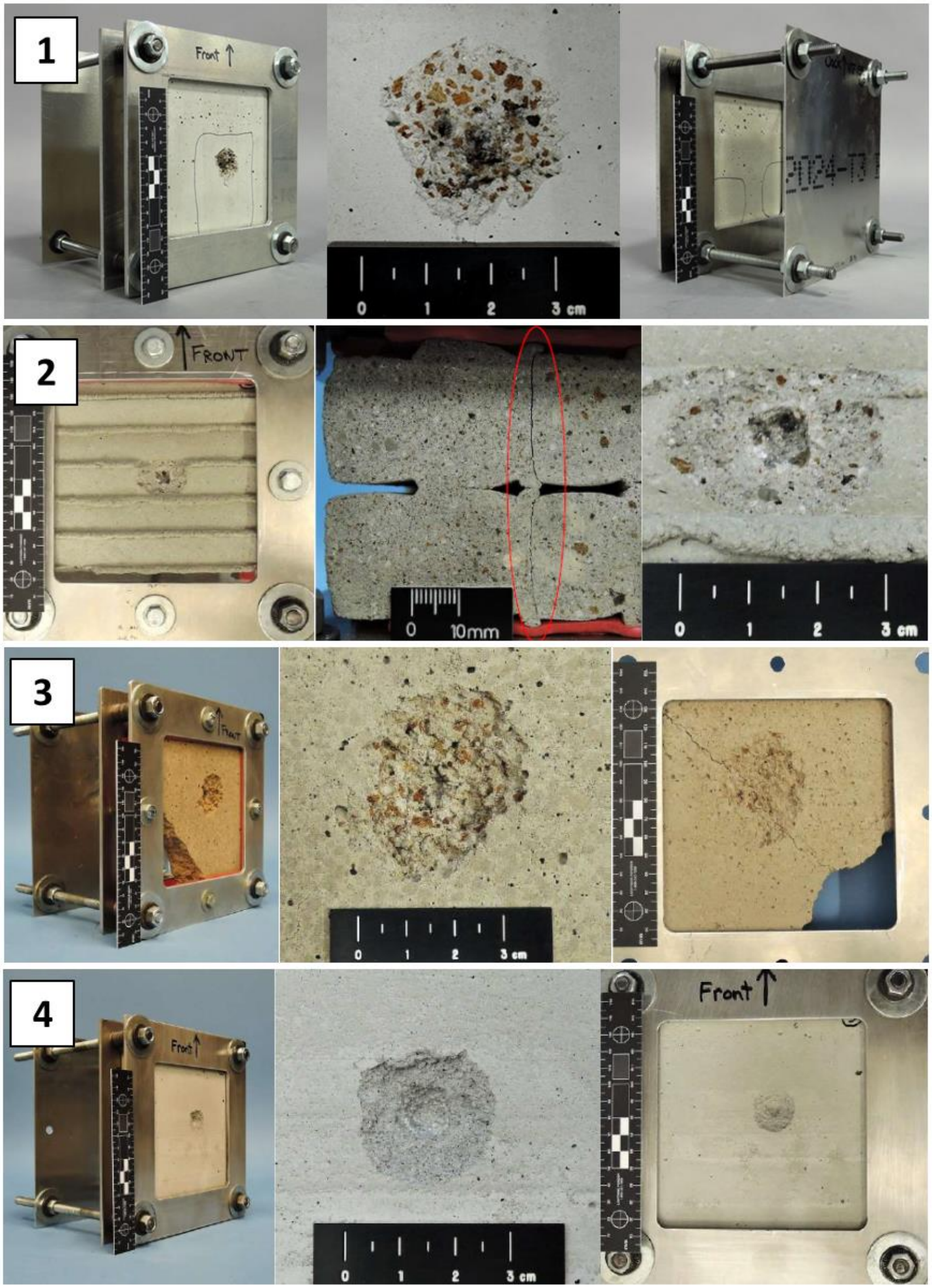

Figure 2: Test Articles after impact; each row shows different views of the same article. Note break along layer interface in Test Article 2, and spallation and cracking of Test Article 3 (right image, row 3). Simulant grains are red/orange and black.

Conclusions and Recommendations

A comparison of the Test Articles led to the following conclusions and recommendations:

- Sorel cement has a compressive strength up to 8000psi [7]. Test Article 3 (the Sorel sample) did not hold up to impact as well as expected, potentially due to the relatively large amount of set retardant (boric acid) required to use this material in additive construction processes.
- Layered samples stand up to hypervelocity impact as well as non-layered samples, an important result for the USACE team.
- Impact testing of layered samples delaminates layers deposited and cured on different days, thus any additional layered hypervelocity impact test articles should be printed on the same day.
- Additional testing must be completed to determine if simulant grain size, simulant crystallinity, rheology control, or the layering process infuences crater size.
- Ideally, glass spheres will be used in future testing to further mimic micrometeorite impacts.

References

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