CONSTRUCTION MATERIAL PROCESSED USING LUNAR SIMULANT IN VARIOUS ENVIRONMENTS

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ABSTRACT

The manufacture of construction materials from locally available resources in space is an important first step in the establishment of lunar and planetary bases. The objective of the CoMPULSIVE (Construction Material Processed Using Lunar Simulant In Various Environments) experiment is to develop a procedure to produce construction materials by sintering or melting Johnson Space Center Simulant 1 (JSC-1) lunar soil simulant in both earth-based (1-g) and microgravity (~0-g) environments. The characteristics of the resultant materials will be tested to determine its physical and mechanical properties. The physical characteristics include: crystalline, thermal, and electrical properties. The mechanical properties include: compressive, tensile, and flexural strengths. The simulant, placed in a sealed graphite crucible, will be heated using a high temperature furnace. The crucible will then be cooled by radiative and forced convective means. The core furnace element consists of space qualified quartz-halogen incandescent lamps with focusing mirrors. Sample temperatures of up to 2200°C are attainable using this heating method.

INTRODUCTION

The GAS-072 payload consists of an experiment designed and developed by the CoMPULSIVE team: student members of Orange Coast College Research Club (OCCRC), California State University, Long Beach Extension Program (CSULB), and California State Polytechnic University, Pomona (CAL POLY). Technical support is provided by a group of Orange County Section American Institute of Aeronautics and Astronautics (AIAA) engineers, scientists, and consultants.

The establishment of a long term human base on the moon presents many challenges. The production of suitable construction materials must meet several criteria. Due to the high transportation costs of raw materials from Earth, to be cost effective, any production method should utilize as much local lunar material as possible. To keep the production cost low the process should be simple and the required hardware and labor should be minimized. The final product should have the properties to withstand the harsh environmental conditions on the Moon. In the lunar environment there is a near absolute vacuum, a total lack of atmosphere and weather, and continuous exposure to galactic cosmic radiation and solar flares. The lunar surface temperature ranges from 127°C to -173°C. The lack of atmosphere means that there is no convection to help equalize temperatures between the sunlit and shaded sides of any construction. Thus for points in close contact very large temperature differences can exist. Also, any structure will be subjected to a constant bombardment of meteorites and micrometeorites.

It has been proposed (ref. 1) to use sintering or cast basalt manufacturing in the early stages of lunar base establishment. Both of these techniques heat the lunar soil to the melting temperature and then let it cool gradually. Among the heating methods proposed are concentrating solar energy, using electric (resistance) furnaces and microwave irradiation.

EXPERIMENT OBJECTIVES

The lunar simulant prepared by both the University of Minnesota (MLS-1) and NASA Johnson Space Center (JSC-1) has been successfully sintered and melted. The resulting sample was tested as a construction material (ref. 2,3). In particular, McDonnell Douglas (ref. 4,5,6) investigated the feasibility of using a solar array to focus direct sunlight onto a sample of lunar soil. The prototype solar array produced columnar bricks possessing various degrees of structural integrity.

It has been proposed that samples produced by sintering or melting in microgravity may have a more homogenous distribution of basaltic components upon resolidification and could produce a material with a smaller grain size. Fine grain structures have greater compressive strength and ductility. Presently, no known material processing work has been conducted with lunar soil simulant in a microgravity environment.

The objective of the CoMPULSIVE experiment is to sinter or melt a sample of lunar soil simulant in a Shuttle Get-Away-Special (GAS) canister. The specimen obtained once the experiment has been flown will be tested to determine its compressive strength, ductility, density, crystalline structure, thermal, and electrical properties. This data can be compared to samples processed on earth to determine if there is any change in properties. If there is a change, the 1-g and near 0-g data can be interpolated to predict the properties of the material formed by heating and cooling lunar soil in the lunar environment.

EXPERIMENT DESCRIPTION

The experiment will be housed in a NASA provided 0.142 cubic meters GAS canister. A schematic diagram of the test setup is shown in Figure 1. A cylindrical specimen (1.27 cm diameter, 3.81 cm height) of lunar soil simulant (JSC-1) in powder form will be encased in a pyrolytic graphite crucible. The crucible will be surrounded by six halogen bulbs positioned 60 degrees apart around the long axis of the sample. Each bulb has a gold-plated reflector to optimize heat transfer. The entire assembly will be placed in the pressurized vessel.

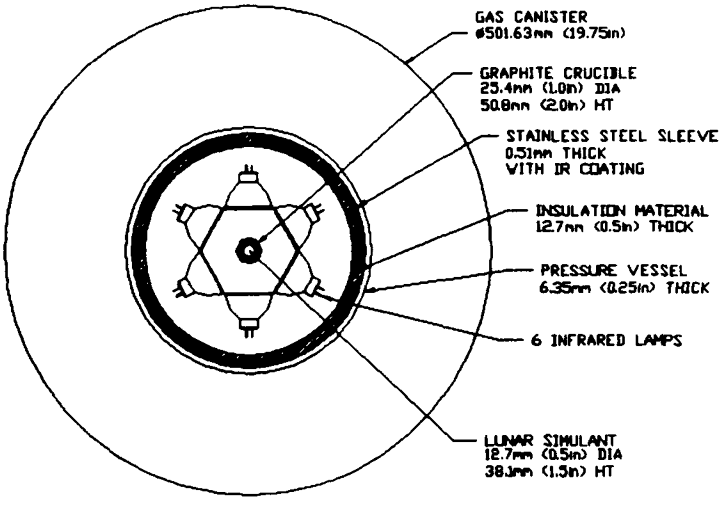


Figure 1. Schematic Diagram of the CoMPULSIVE Project

The power supply required to heat the sample may be provided by 32 Gates model BC 2 Volt batteries. An astronaut will start the experiment by switching on the GAS control decoder (GCD) system on the shuttle during a quiet period for the crew. Thermocouples will monitor the temperatures during the experiment. The temperature and other vital parameters will be monitored using an automated data acquisition system.

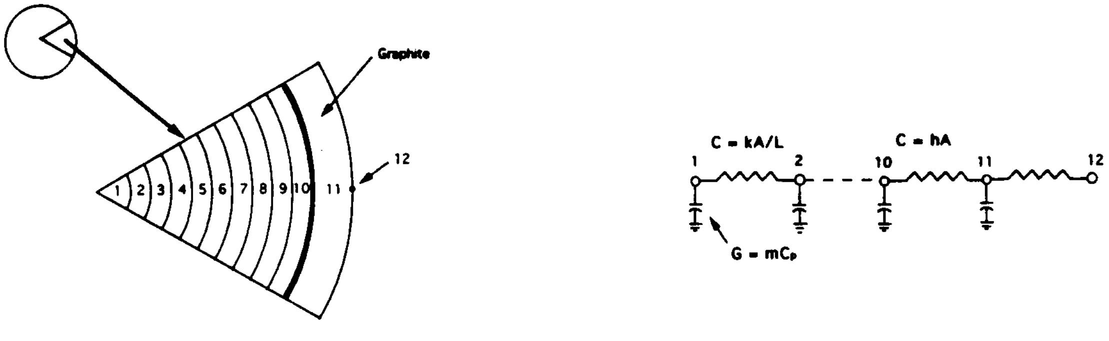
The post-flight ground control test will duplicate the entire flight experiment after the experiment is flown on the space shuttle and will be used as the control sample.

TECHNICAL TASKS

The technical tasks have been divided into five categories: Thermal Analysis; Furnace Design; Power; Control, Monitoring, and Data Acquisition Systems; and Structure. The thermal analysis and furnace design are critical design elements, setting the requirements for the remaining components.

Thermal Analysis

A thermal model of the furnace has been developed using the Systems Improved Numerical Differencing Analyzer (SINDA). It has been used to predict the temperature histories of the lunar soil simulant and furnace components. The SINDA model of the lunar soil simulant, crucible, and furnace is a transient (time-varying), one-dimensional radial system which is composed of multiple nodes. In addition to the furnace, a thermostatically controlled power source is also included. Figure 2 shows a discretized resistor network and the nodes used in modeling the system. Note that results presented do not include modeling of the insulated pressure vessel.



Thermal Model

Equivalent Electrical Analog

Figure 2. Resistor Network Schematic of SINDA Model

The assumptions used in the model are as follows:

1. Thermal conductivity and specific heat are constant with temperature.
2. Ideal bulk properties of the lunar soil simulant are used. In reality, density varies with porosity, compaction, and state (solid or molten).
3. The heat of fusion of lunar soil simulant is constant and is assumed to be 2337 J/kg.
4. Modeling of contact resistance between particles, flow of molten soil through pores, etc., are not considered.
5. The crucible does not decompose.

The following steps are being taken to update the SINDA model:

1. Modeling of the insulated pressure vessel and new furnace designs.

2. Using temperature dependent thermal conductivity and specific heat properties.
3. Modeling of the phase change in the JSC-1.

The SINDA model results have raised the following issues:

1. Processing of the JSC-1 currently takes too long and may exceed the time available in orbit.
2. Temperature gradients may cause thermal stresses and cracking during cool-down.

The issues and limitations of the SINDA thermal model indicate a need for testing to determine the feasibility of the JSC-1 melting experiment as currently specified.

Furnace Design

The purpose of the furnace is to sinter or melt a sample of JSC-1 of a given size and shape. Additionally, the furnace must also be able to regulate the heat transfer rates during both the heating and cooling phases of the sample processing cycle. In order to achieve this, the furnace is comprised of four major components: Heating Elements, Simulant Containment, Heat Transfer Control, and Pressure Vessel.

First and foremost is the heating element. This device takes the energy stored in the batteries and transforms it into thermal energy in the sample. The heating elements will consist of six 15V, 150W lamps arrayed radially around the sample as shown in Figure 1. The radiated energy emitted from the bulbs is expected to raise the temperature of the JSC-1 from 289 K to 1513 K.

Second is the simulant container. This component is responsible for containing the sample during the entire processing cycle. The simulant will be processed in a pyrolytic graphite crucible. This material was chosen because of its high strength, high thermal conductivity, and superior dimensional stability at high temperature. Because of this dimensional stability, it is highly unlikely that the crucible will bind with sample when cooled from the processing temperature.

Third, there must be a method of controlling heat transfer from the various components of the furnace. First, there must be a controlled cooling of the sample. This is needed to prevent cracking due to thermal stresses, as well as to control the final properties of the processed simulant. Second, the furnace should be insulated. This would help minimize the amount of heat loss from the furnace and consequently minimize the electricity which is consumed in the experiment. This will also serve to protect the other components contained within the GAS canister.

Finally, a pressure vessel is required to maintain a vacuum within the furnace. The use of a pressure vessel will contain any outgassing byproducts, and serve to optimize the heat transfer environment within the furnace.

These four components will comprise a furnace system which will be able to accurately control both temperatures and heat transfer rates.

Power

A controlled power system will provide electricity to the furnace and the data acquisition system. This power system will help prevent excessive temperatures in the heating components, thus minimizing the power being drawn from the batteries.

The power system consists of an active controller, batteries, battery case, and battery vent. Thirty-two Gates model BC batteries have been selected to provide the required power. Each battery has a mass of 1.58 kg and 2 V dc. Therefore, thirty-two batteries are needed to generate 3,121 W to sinter or melt the JSC-1.

Control, Monitoring, and Data Acquisition System

Control, monitoring, and data acquisition systems are needed to control the heater duty cycle and to record data, the conditions under which the JSC-1 was processed. The components which comprise the system include: relays, switches, wiring, voltmeters, ammeters, thermocouples, pressure transducers, controller hardware and software.

Structure

The structure holds the entire GAS project together and prevents Shuttle launch loads from affecting components. The experimental components will be held by the structure which will in turn be cantilevered from the NASA provided mounting plate. A vibration isolation system may be used to prevent damage to sensitive components. This system may also be used to protect the specimen from damage during shuttle operations and reentry. Finally, bumpers will prevent the experiment from hitting the sides of the canister.

PROJECT MANAGEMENT

The Project faculty adviser is Dr. Ernest W. Maurer, the Dean of Technology at Orange Coast College (OCC). The main contingency of active participants is comprised of student members of the OCC Research Club. The key members of the research club include: Stan Chase, Michael Kindig, John King, Kevin Montegrande, Raymond Norris, Bridget O'Callaghan-Hay, Ryan Van Scotter, and Jonathan Willenborg. These members are concentrating on project management, budgeting, research, thermal analysis, safety, tooling, and manufacturing.

The GAS Project Committee Chair is Harry Staubs, the lead representative of the AIAA Orange County Section. Harry is serving as the NASA payload manager. Joseph Morano, the President of the AIAA Orange County Section, is the NASA customer contact.

The schools, CSULB and CAL POLY, have taken on the focuses of furnace design and support structural design, respectively. Members of the CSULB team include Michael Petran, Ed Tate, and Tim Williams. The CAL POLY team members are Phong Chen, Campbell Dinsmore, Lincoln Le, Gautam Shah, and Phat Vu.

Technical support has been provided by a team of consultants. This team includes: Aaron Ayotte, Brian Dubow, Ralph Housman, and Jim Perez.

TEST PROGRAM

The test program is divided into four stages: Critical Technology Test, Ground Test, Flight Test, and Post Processing Test.

Critical Technology Test

A test will be conducted to sinter or melt JSC-1 in a ground test configuration using a power supply to establish the power requirements. This will help to optimize the test sample size and the flight battery pack configuration. This test will be conducted to verify that the experimental apparatus functions correctly and ensure that the flight test can be successfully accomplished.

Flight Test

Gas Payload G-072 will melt a specimen of JSC-1. The heater will be started by a power-up GAS Control Decoder relay 'A' command which will be activated by the Shuttle crew. A JSC-1 specimen will come to temperature equilibrium at 1240°C within 36 to 48 hours after power-up. This time is based on a preliminary thermal analysis from the SINDA thermal model. Power to the sample will be cycled on and off to optimize the use of on-board available battery power. Once the target temperature is reached, the specimen will be allowed to cool in a controlled manner to avoid thermal stresses that could adversely affect structural integrity of the specimen.

Ground Test

A ground test will be conducted using the actual flight hardware. This test will be conducted to obtain control data at 1-g which will be used in conjunction with near 0-g data to interpolate the results to the gravitational pull of the moon. Several specimens will be made for test controls.

Post Processing Tests

Both the earth bound and the Shuttle borne sample sets will have their physical and mechanical properties evaluated. The physical tests to be performed will determine the density, thermal properties, electrical conductivity, and crystalline structure of the samples. The mechanical tests to be performed will determine the compressive strength, the tensile strength, the flexural strength, and modulus of the samples.

CONCLUSIONS

A simple and economical method has been proposed to obtain data for the properties of sintered or melted lunar soil. The data accumulated from the near 0-g environment will be compared to the earth ground test. An interpolation will be made to determine the data for a lunar 1/6-g environment. These results are required by researchers and engineers who will be designing structures to be built on the lunar surface.

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