

Microwave Sintering of Simulated Moon Rock

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Abstract

The focus of this research was to determine the feasibility of using microwave energy to sinter simulated moon rock. Microwave processing is often used as an alternative to traditional sintering of ceramic materials for its energy efficiency and decreased sintering times. In lunar applications, microwaves would be a more useful for sintering than traditional methods because microwave devices may be transported more easily and with less cost. As found, moon rock does not have the needed physical and thermal properties suitable for its use as a structural material for a lunar base or orbiting structure.^[1,2] However, sintered moon rock may have those required characteristics. To evaluate the potential for using microwave energy to sinter simulated moon rock, both stand-alone and hybrid heating methods were tested. Based on collected data, an 1100-watt commercial microwave oven can emit enough energy to rapidly reach the sintering temperature of moon rock using hybrid heating methods. Further research needs to be conducted to compare the physical characteristics of moon rock sintered conventionally and with microwave energy.

Keywords: Microwave sintering, simulated moon rock, regolith

1. Introduction

The construction of a lunar station has been stifled by the limitations of earth-moon transportation, namely the large expense of carrying the additional mass and volume of construction materials upon space shuttles.^[1,2] A seemingly simple solution to this transportation problem is to use the available materials on the moon to build structures.

1.1 Lunar Soil and Simulants

In order to understand how these materials may be processed in a microwave field, it is important to understand how materials act in a microwave field. Research divides materials into three categories when microwave processing is discussed. Materials can be opaque, transparent, or absorbent under microwave energy.^[3] The main property that dictates which category a material belongs to is the dielectric loss of the material. If there are differences in dielectrics within a given material, the microwaves will interact differently with each phase, creating local inhomogeneities. A combination of liquid and solid phases develops (transient liquid-phase sintering), resulting in improved mechanical properties. This type of heating is a likely outcome for materials with various constituents like lunar rock.^[2]

Since as found moon rock does not have the needed physical and thermal properties that will allow its use as a structural material for a lunar base, it will be necessary to sinter this material.^[1,2] The sintered moon rock may have the required characteristics to make it a structural material. The development of microwave processing technology could allow moon rock to be used as a structural material, bypassing the expense of bringing materials to the moon.

The material used in this study is similar to the dust found on the moon's surface, with the major difference being that the dust on the moon contains a nanophase iron on its surface. The presence of nanophase iron on the surface of real lunar soil grains is particularly beneficial to microwave processing. The nanophase iron particles add to the adhesion and strength of the overall aggregate also creating additional fusion of particles. Nanophase iron on the surface of grains forms fine melts acting as a glass binder (thus providing a transient liquid-phase sintering situation).^[2] Since the stimulant used in this study does not contain this phase, it was expected that research using this stimulant would be more difficult than the actual process may be.

1.2 Microwave Technology

In many instances, microwave processing improves upon conventional heating methods because it can provide a precisely controlled, energy-efficient method of heating. This efficiency stems from one of the intrinsic characteristics of microwave processing – volumetric heating. For materials that are almost transparent to microwaves, stand-alone microwave processing will heat the materials from the inside to the outside, allowing for reduced sintering times and temperature. Also, microwave processing has been used in conjunction with conventional processing to achieve an improved uniformity that neither could achieve singularly. The combination of microwave processing and conventional sintering is known as microwave hybrid heating.

Current literature suggests that only limited studies of the traditional sintering process of regolith have been performed. The addition of a microwave sintering study of regolith would fill this gap in current research.^[2]

This paper discusses the use of microwave hybrid heating to sinter pressed regolith pellets in 700-watt and 1100-watt commercial microwaves.

2. Experimental Procedure

The consistent production of uniform sample pellets greatly determined the repeatability of this research. Microwave energy absorption within the pellets may have differed with density gradients, porosity, and general pellet uniformity, and this variation may have affected the sintering process and the resulting sample characteristics.

2.1 Sample Pellet Preparation

A three-piece die assembly was used to produce cylindrical pellets under bi-axial loading conditions. The die was cleaned thoroughly to ensure no loose powders, dust, or debris remained on die surfaces. After cleaning the surfaces, a release spray was used to lubricate the die cavity.

Approximately 0.3 grams of dry raw regolith powder was measured using a laboratory scale accurate to three decimal places. One drop of room temperature tap water was then added to the powder using a pipette. Following the addition of water, the slurry was mixed with a small utensil to evenly distribute the water until the powder became moist and clay-like. The wet mixture was placed in the die and pressed at 9800 psi at room temperature. The sample was removed and then dried at 100°C for one hour in a conventional oven.

2.2 Microwave Modifications

Commercial microwaves have historically varied their energy output by using a duty cycle function. The duty cycle

determined length of time the power cycles on and off and is pre-programmed for each power setting. Most home-model microwaves are not equipped for measuring high temperatures.

The first modification was to enable temperature measurement capabilities, as shown in Figure 1. Two thermocouples could be inserted from the top of the microwave cavity and measure two different temperatures simultaneously, which is done to verify a functioning hybrid heating setup.

Other modifications included sealing the microwave cavity to prevent the leaking and the removal of extraneous electronic equipment to reduce the complexities of the system.

2.3 Sintering Study

For the initial hybrid heating tests, the moon rock powder was contained in a quartz crucible which was placed inside of a larger quartz crucible containing silicon carbide (SiC). The entire setup was then placed onto a piece of space shuttle tile (high temperature reusable surface insulation – silica based) as shown in Figure 1.

The wet-pressed pellet samples were used in the testing of a 25 wt % SiC - 75 wt % alumina (Al_2O_3), susceptor casket for use in hybrid heating sintering. The casket was tested on different power settings and for different time periods in an effort to create a sintering profile for the casket. The setup for these tests is shown in Figure 2.

Wet-pressed pellet samples were also processed in a conventional furnace to act as a control group against the microwave-sintered samples. These conventionally sintered samples were used to determine acceptable relative density and possible microstructure of a sintered sample of simulated moon rock.

2.3 Data Analysis

The temperature measurements for all of the stand-alone and hybrid heating powder tests were plotted and analyzed to determine the feasibility of using each method for sintering. The data collected from the 700- and 1100-watt microwaves were compared to determine how the differences in power level affected

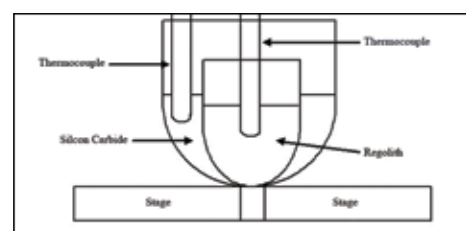


Figure 1. Schematic of hybrid heating w/ powder

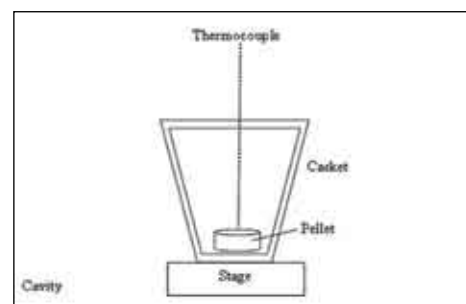


Figure 2. Schematic of susceptor casket w/ pellet

the temperatures achieved in stand-alone and hybrid heating methods.

Temperature measurements from both the hybrid heating and stand-alone heating methods were used to determine the feasibility of sintering simulated moon rock. The temperature profiles obtained from these tests were used to make comparisons between heating rates in each processing method.

3. Results and Discussion

The initial microwave absorbcency test was designed to demonstrate the capability of regolith to absorb microwave energy at room temperature. The melting temperature of regolith, as taken from the literature, is approximately 1100° C.^[9] An ideal sintering temperature is approximately two-thirds of the melting temperature, or about 750 °C.

As shown in Figure 3a, the temperature measured in the stand-alone set up was not sufficient to reach the desired sintering temperature. This plot shows the temperature of regolith as it heated in the 700-watt microwave oven on high power for ten

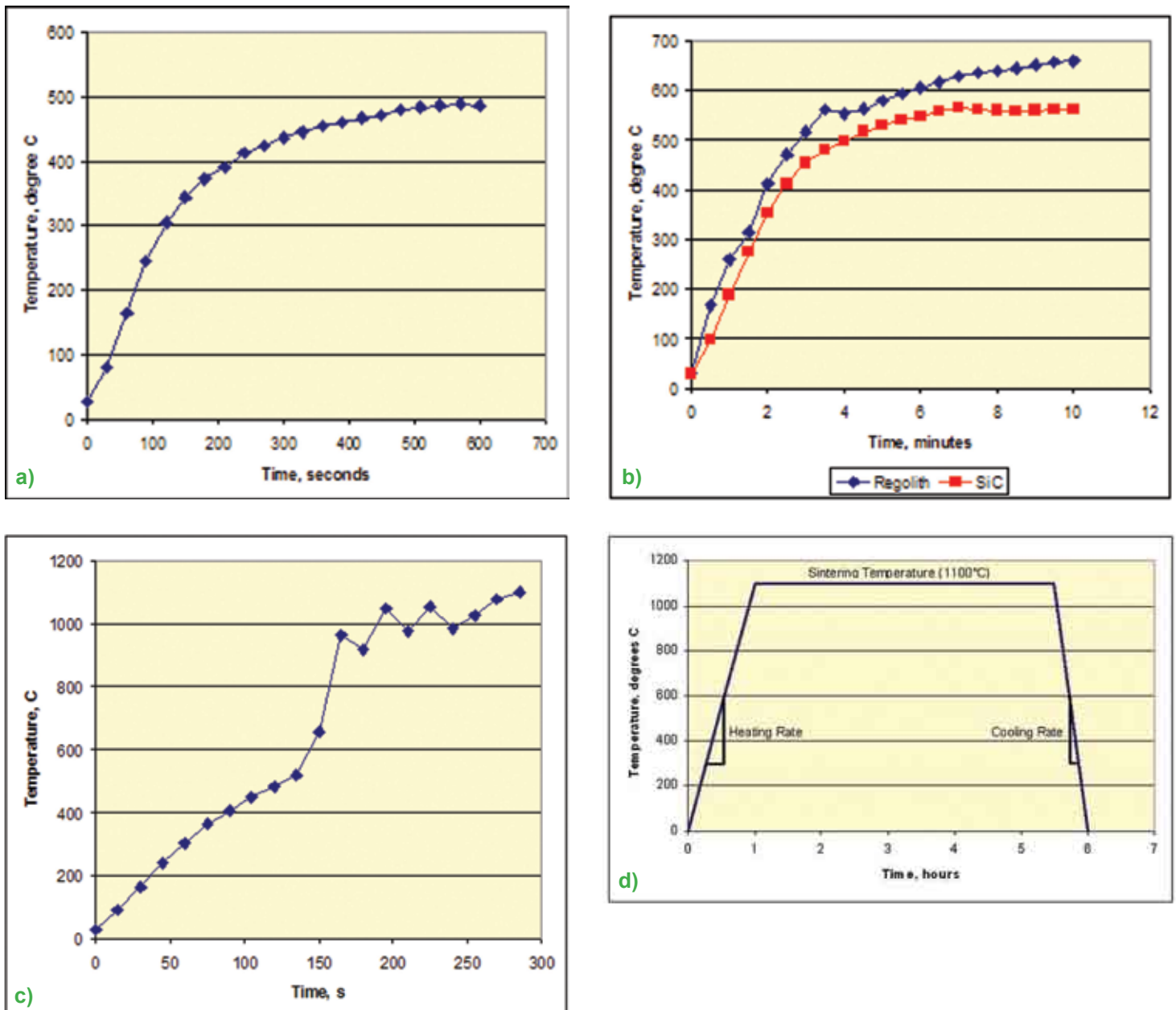


Figure 3. Heating curves for: a) stand alone microwave absorbcency test 700-watt microwave, 100% power b) hybrid heating of powered simulated moon rock 700-watt microwave, 80% power c) susceptor heating of pellet 1100-watt microwave, 80% power d) sintering profile for conventional processing of pellet

minutes. As the graph suggests, regolith could not be sintered using this technique because the temperature plateaued at only 500 °C.

A hybrid heating setup was created to enhance the absorption characteristics of regolith. Typically an increase in the ambient temperature of a microwave absorbent material will increase its ability to respond to microwave energy during hybrid heating. This setup was tested on 80% power for ten minutes in the 700-watt microwave. Figure 3b shows the temperatures of both the regolith powder and the silicon carbide used to heat the regolith.

The temperature of the regolith plateaued just under the 700 °C mark. Although this was still below the desired sintering temperature, it was significantly greater than the temperature achieved by stand-alone microwave processing. This test demonstrated that hybrid heating could obtain higher temperatures with lower power settings when compared to the stand-alone at full power.

The data also suggested that both the regolith and the silicon carbide were not absorbing significant amounts of microwave energy. Silicon carbide alone often reached peak temperatures (~1200 °C) within two minutes of microwave heating. Given that the silicon carbide could not reach its peak temperature after ten minutes, it was not absorbing much microwave energy.

As a result, the data suggested that even with hybrid heating, a 700-watt microwave was not sufficient to sinter our regolith composition. All tests completed after this point were completed in the 1100-watt microwave.

The use of a susceptor casket (25 wt% SiC-75 wt% Al₂O₃) and a pellet was the ideal laboratory setup. This setup was heated at 80% power for four minutes and 45 seconds in the 1100-watt microwave. Figure 3c and 3d shows the heating of the regolith pellet in comparison to a conventional heating curve and illustrates the differences in time required to process using hybrid heating instead of conventional processing. Figure 3 illustrates the ability of regolith to reach its sintering temperature using a susceptor casket containing 25 wt% SiC. In addition, a lower power setting seemed to help slow down the heating process and to maintain the sintering temperature for longer periods of time.



Figure 4. Regolith glass on tip of thermocouple

The oscillating waves in Figure 3a stem from the data point measurements and the coinciding duty cycle of the microwave.

The result of using a susceptor casket and the 1100-watt microwave was not sintered regolith, but

melted regolith. Figure 4 is a photograph of regolith glass bubble attached to the end of a thermocouple. The ability to reach the melting temperature of regolith indicated one significant fact—the sintering temperature was reached and surpassed.

4. Conclusions

Based on the data collected during this research, the microwave energy from the 700-watt microwave is not sufficient to sinter simulated moon rock. However, the 1100-watt microwave did provide sufficient energy to create microstructural changes, such as melting and sintering. This study also shows that it is possible to heat simulated moon rock much more rapidly using hybrid heating than conventional processing. The rapid heating may allow for unique microstructures that may not be obtained with conventional heating.

5. Future Work

Although this research did not produce sintered samples of simulated moon rock, did result in glass samples of regolith, indicating that sintering is theoretically possible. Research to produce sintered samples of simulated moon rock should be pursued in the future.

Once sintered samples are produced, a study of their mechanical properties should be completed. A comparison of the mechanical properties of conventionally sintered and microwave-sintered samples should also be pursued.

In addition, a detailed study of the differences in microstructure in conventionally and microwave-sintered samples should be conducted to determine what features in the microstructure contribute to the mechanical properties of the final products.

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