COMBUSTION OF LUNAR REGOLITH/MAGNESIUM MIXTURES. A. Delgado, F. Álvarez, C. White, and E. Shafirovich, Department of Mechanical Engineering, The University of Texas at El Paso, 500 W. University Ave., El Paso, TX 79968, eshafirovich2@utep.edu

Introduction: Self-propagating high-temperature synthesis (SHS) has been used for fabrication of numerous ceramic and other compounds. This technique involves self-sustained propagation of the combustion wave over the mixture due to exothermic reactions between the mixture components. The present paper reports recent results of studies on SHS in mixtures of JSC-1A lunar regolith simulant with magnesium, conducted with the goal to develop a low-energy consuming method for the production of construction materials on the Moon.

Prior Research: Thermodynamic calculations for combustion of Al/JSC-1A and Mg/JSC-1A mixtures have shown that Mg provides the highest adiabatic temperatures [1]. Experiments on the combustion of Mg/JSC-1A mixture pellets confirmed that Mg is a promising metal for the reactions with regolith [1].

Minimization of Magnesium Content: In the thermodynamic calculations, the maximum adiabatic temperature in Mg/JSC-1A mixtures, 1417°C, was achieved at 26 wt% Mg [1]. Experiments with a relatively coarse regolith have shown that steady propagation of a planar combustion front requires Mg concentrations of 24 wt% or more. At 23 wt% Mg, a spinning combustion wave with two hot spots moved along a helical path on the sample surface in opposite directions (Fig. 1) [2]. Note that this is the first experimental observation of the spinning combustion wave with two counter-propagating hot spots in solid-solid mixtures.

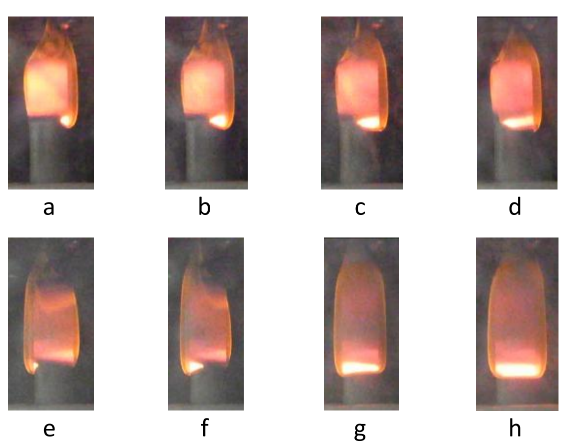

Fig. 1. Images of spin combustion in JSC-1A/Mg pellet (diameter 12.7 mm). Images (a) – (d) show a hot spot that travels from right to left, while images (e) – (h) show a hot spot that travels from left to right.

In lunar missions, it would be desired to decrease the content of Mg that is required for combustion with regolith. To improve the kinetics of reactions between JSC-1A and Mg, the former was subjected to high-energy mechanical milling in a planetary ball mill (Fritsch Pulverisette 7). As a result, the specific surface area of JSC-1A significantly increased and the required concentration of Mg was lowered to 13 wt% [2].

Gravity Effect: To investigate the effect of gravity on the combustion of Mg/JSC-1A mixtures, experiments onboard research aircraft were conducted [3]. The front propagation velocity in the mixtures (26% Mg) was determined during the periods of reduced and increased gravity. Figure 2 indicates a slight trend toward a higher velocity with increasing gravity though the scatter hinders reliable conclusions.

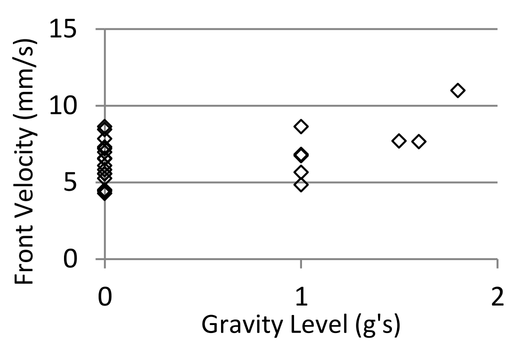

Fig. 2. Combustion front velocity as a function of gravity [3].

Increasing the Strength of Products: In prior experiments with Mg/JSC-1A mixtures, the combustion products were not sufficiently strong for using them as construction materials. The product composition and strength may depend on heat transfer from the pellet to the surroundings during combustion and subsequent cooling. In the present paper, the heat transfer was changed by submerging the pellet in silica and JSC-1A powders.

For these experiments, JSC-1A was milled in the planetary ball mill and mixed with 325-mesh Mg powder. The mixtures (26% Mg) were compacted into pellets (diameter 25.4 mm) using a hydraulic press (19.6 kN). The pellets were wrapped with a 3 mm thick ceramic fiber insulator. A thermocouple in a two-channel ceramic insulator was inserted into each pellet and connected to a data acquisition system. Two types of thermocouples were used: W/Re5% - W/Re26% (type C, Omega) and Chromel-Alumel (type K).

The pellets were submerged in either JSC-1A or silica powder, located in an aluminum can (Fig. 3). The can was placed in a chamber connected to an argon cylinder and a vacuum pump. During the experiment, the pellet was ignited at the top by a Nichrome wire connected to a DC power supply. The experiments were conducted in argon at 90 kPa.

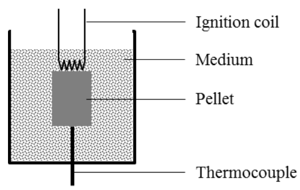

Fig.3. Schematic of the pellet location in the can.

The use of silica as the surrounding medium resulted in the highest strength of the obtained materials. In contrast with the products obtained with no surrounding powder, these materials could not be easily broken (it was possible to only cut them using a saw). Figure 4 shows a photograph of the combustion products obtained in silica environment.

Fig. 4. Cross-section of the product pellet obtained by combustion of Mg/JSC-1A pellet submerged in silica.

Figure 5 shows typical results of temperature measurements. The maximum temperature was 1350-1400°C independently on the environment. It is seen that the use of silica leads to a higher cooling rate immediately after combustion, but the effect becomes the opposite at temperatures lower than 1000°C.

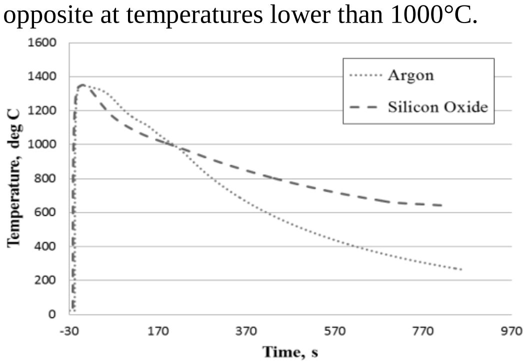

Fig.5. Time variation of temperature during combustion of Mg/JSC-1A pellets in argon (dotted) and silica (dashed) environments. Time "0" corresponds to the maximum temperature.

Figure 6 shows XRD patterns of the products. The highest peaks in both patterns correspond to MgO. The observed differences in other peaks indicate that submerging the sample in silica slightly changes the composition of the combustion products, which include Si and complex oxides of Al, Mg, and Si [1, 3]. Additional studies are required to explain the observed high strength of the products obtained during combustion of Mg/JSC-1A pellets submerged in silica.

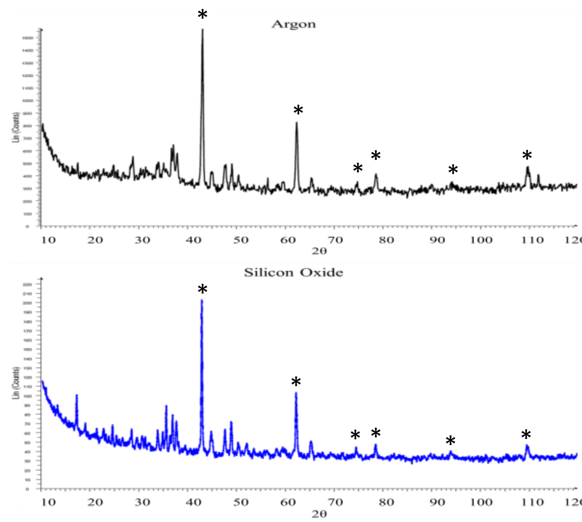

Fig.6. XRD patterns of products obtained in argon (top) and silica (bottom) environments. Asterisks indicate MgO peaks.

Conclusions: Combustion of Mg/JSC-1A mixture pellets has been studied experimentally. At low concentrations of Mg, spin combustion with two counter-propagating hot spots occurs. High-energy ball milling of JSC-1A allows one to obtain combustible mixtures at Mg concentrations as low as 13 wt%. The effect of gravity on the combustion of Mg/JSC-1A pellets is small. Submerging the pellets in silica during combustion significantly increases the strength of the products.

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References: [1] White C., Alvarez F., and Shafirovich E. (2011) *J. Thermophys. Heat Transfer*, 25, 620-625. [2] Álvarez F., White C., Narayana Swamy A.K., and Shafirovich E. (2012), *34th International Symposium on Combustion, July 29 – Aug. 3, 2012, Warsaw, Poland* (accepted). [3] Álvarez F., Delgado A., Frias F., Rubio M., White C., Narayana Swamy A.K., and Shafirovich E. (2012) *50th AIAA Aerospace Sciences Meeting, Nashville, TN, Jan. 9-12, 2012*, AIAA Paper 2012-1119.