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Solidification Furnace for Microgravity Experiments on Sounding Rockets

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Abstract: *The Brazilian Microgravity Program is mainly based on experiments carried out on sounding rockets. Up to present days, three missions carrying a total of 25 experiments were made. In all flights, a fast solidification furnace, capable of producing temperatures up to 900º C, was used to process metal and semiconductor alloys in microgravity environment. This paper has described the furnace and the solidification experiment made during the last parabolic flight, called Maracati Mission, which has occurred in December, 2010.*

Keywords: *Microgravity, Suborbital flights, Solidification furnace, Alloys solidification.*

INTRODUCTION

The Brazilian Microgravity Program, which is supported by the Brazilian Space Agency (AEB), selects microgravity experiments, providing partial financial support for the approved projects since their initial design phases up to the flight mission.

The Microgravity Program has contemplated missions on the International Space Station (ISS) in 2006 (Bandeira et al., 2007) and on the Brazilian made sounding rockets (Corrêa et al., 2005). The first parabolic flight was in 2002, and eight microgravity experiments were selected by the First Announcement of Opportunity (AO) of the program, in areas such as Biology, Material Sciences, and Transport Phenomena. The experiments were launched from the Brazilian Alcântara Launching Center (CLA), onboard an one-stage Brazilian VS-30 sounding rocket (three to four minutes of microgravity), made by the Institute of Aeronautics and Space (IAE), from the Aerospace Technology and Science Department (DCTA).

A second flight was done in 2007 and a third in 2010 with a more powerful two-stage sounding rocket, which is denominated VSB-30 (six to eight microgravity minutes). This rocket is capable of transporting payloads with mass up to 400 kg during about 360 seconds in a ballistic flight above 200 km. After the parabolic flight it fell into the sea aided by parachutes and was recovered by the Brazilian Air Force helicopters.

The payload platform used to carry the experiments was made by the German Aerospace Center (DLR/MORABA) in cooperation with IAE (Garcia *et al.*, 2011), and is shown in Fig. 1, together with the VS-30 and VSB-30 rockets.

Figure 1. Brazilian sounding rockets and microgravity platform.

SOLIDIFICATION FURNACE

A group of the Brazilian Space Research Institute (INPE) has proposed to project, construct, and qualify a compact furnace as a permanent facility for the sounding rockets microgravity program in order to be used by several groups

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that worked in that area (Bandeira *et al*., 2002 and 2007). The purpose of the furnace is to melt and solidify metals and semiconductor alloys with fusion point up to 900ºC. The furnace should be capable of a fast cooling, compatible with the short microgravity times of suborbital flights, in order to solidify samples up to 10 mm diameter and up to 120 mm length.

The tubular furnace was heated and controlled from the ground through the rocket umbilical cable until it reached the desired temperature. After launch, the temperature was kept by thermal inertia. As soon as the microgravity environment was reached, a motor drove the hot part of the furnace to an upper position in less than eight seconds, while the sample remained fixed at the cold region and a fast cooling was obtained. Figure 2 shows the furnace in the two positions described. At the right side of the furnace, there is the electronics control box. It contains a data logger for the type K thermocouples, batteries for the furnace drive motor, timer for motor stopping, amplifier for telemetry temperature signals and the circuit for the control thermocouple and power cables connected to a controller unit and a 110 DCV source, which powers the furnace from the ground, providing a temperature stability of ±1ºC.

Figure 2. Solidification furnace in its two working phases: positioned at the bottom, heating the sample during ground and ascending period, and dislocated to the top permitting a fast sample cooling during microgravity.

The experiment temperature is monitored by thermocouples and their signals are stored in an internal data logger, as well as sent to ground by telemetry.

The exploded drawing of the furnace is shown in Fig. 3. It comprises a tubular furnace made of stainless steel, with 110 mm of diameter and 200 mm of length. The processing chamber of the materials is a ceramic tube with 20 mm diameter, running through the whole furnace length. The upper 120 mm part of the ceramic tube is evolved by a shielded electrical resistance, and quartz fiber is employed as thermal insulation. The remaining resistance free portion produces a thermal gradient between the upper hot section and the cold bottom one in the order of 40ºC/cm. There is an external structure holding the furnace, allowing an up and down movement with the aid of an electric motor. The structure also supports a stainless steel sample holder tube placed inside the ceramic cavity. The system has a total diameter of 180 mm and a total length of 340 mm, weighting around 12 kg.

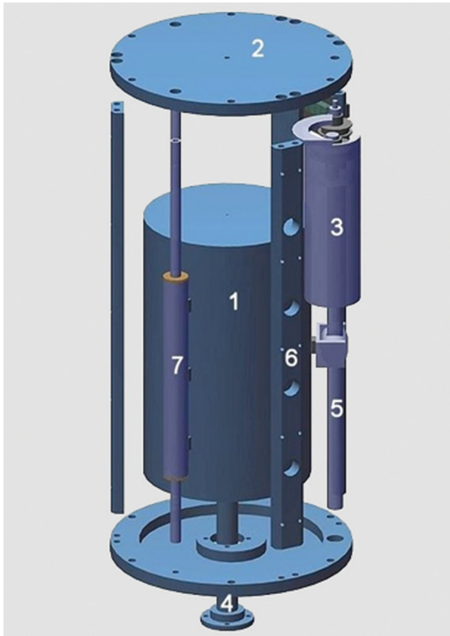

Figure 3. Exploded view of the solidification furnace 1: furnace; 2: top of the external structure; 3: driving motor; 4: sample holder; 5: jackscrew; 6: structural bars; 7: sliding guide bars.

THE MARACATI MISSION

In December, 2010, a VSB-30 rocket departed from the CLA, carrying ten microgravity experiments from Brazilian universities and research centers. The apogee was 242 km and the total flight time was 18 minutes, from which six minutes were in microgravity. The payload fell on the sea and was rescued about one hour later. The experiments included the solidification furnace described, made at the Sensors and Materials Associate Laboratory (LAS), at INPE (An *et al*., 2011).

In this flight a solidification experiment with two eutectic alloys was carried out. The eutectic composition (10.9 Pb at. %) of the PbTe alloy with a fusion point of 410ºC, and the eutectic composition (26.1 Pb at. %) of the PbSn alloy, fusion point of 183ºC, were used.

Each sample, with 13g mass, was sealed under vacuum within a quartz ampoule with 60mm length and 10mm diameter shown in Fig. 4.

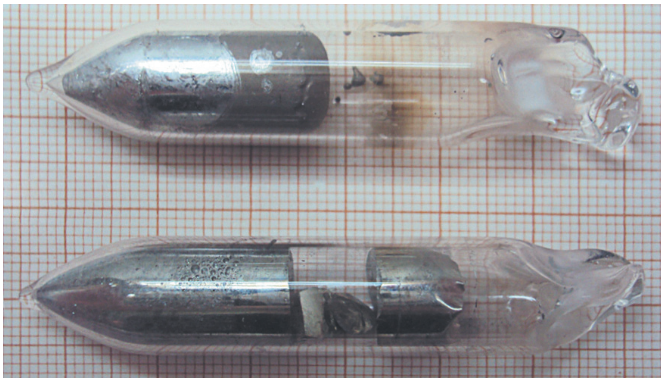

Figure 4. Eutectic $Pb_{10.9}Te_{89.1}$ (top) and $Pb_{26.1}Sn_{73.9}$ ampoules after the microgravity flight.

The ampoules were fitted inside the stainless steel tube sample holder and the furnace was heated in the ground to a set point of 450ºC, using the rocket umbilical cable 30 minutes before launch. The sample temperatures were monitored by the on-board data logger as well as by telemetry, and the furnace temperature gradient is shown in Fig. 5.

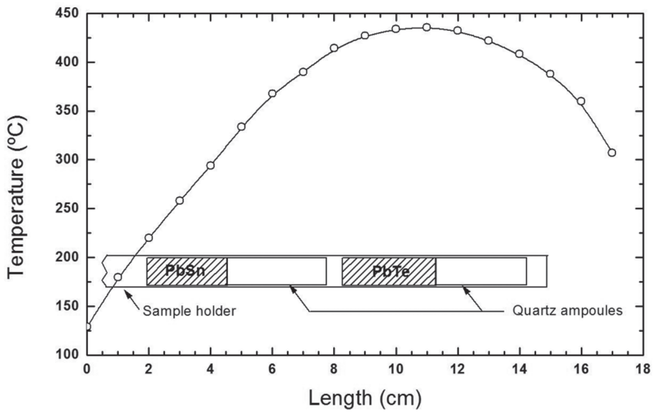

Figure 5. Temperature gradient of the solidification furnace showing the position of the samples quartz ampoules inside the sample holder.

The microgravity level attained was in the order of 10^{-4}g, which was enough to cause predominance of Marangoni convection over the thermal and constitutional gravitational dependent convections, which will allow the study of the superficial tension influence in the PbTe and PbSn eutectic alloys.

All launching procedures and flight phases occurred as planned. When the rocket was launched, the furnace power was switched off. The two-stage rocket worked nominally and the payload reached microgravity about one minute after launching. As the acceleration sensor detected the microgravity proper level, it sent a signal to the furnace and the heater part was moved to the top of the system in eight seconds, leaving the samples free to cool down.

After six minutes, the payload started the reentry trajectory. The parachutes were opened at the proper altitude, the payload fell, and floated in the sea and was later recovered by a Brazilian Air Force (FAB) diving team.

The cycle behavior was as expected, the furnace temperature had a small drop of about 10ºC during the rocket ascending, due to one minute without power. Reaching microgravity, as soon as the furnace moved to the upper position, after 30 seconds, the temperature drop was of 150ºC for the PbTe alloy and 60ºC for the PbSn alloy, allowing the fast cooling needed for both eutectic $Pb_{10.9}Te_{89.1}$ and $Pb_{26.1}Sn_{73.9}$ solidification experiments.

The telemetry data for the furnace thermal cycle are shown in Fig. 6 for both samples.

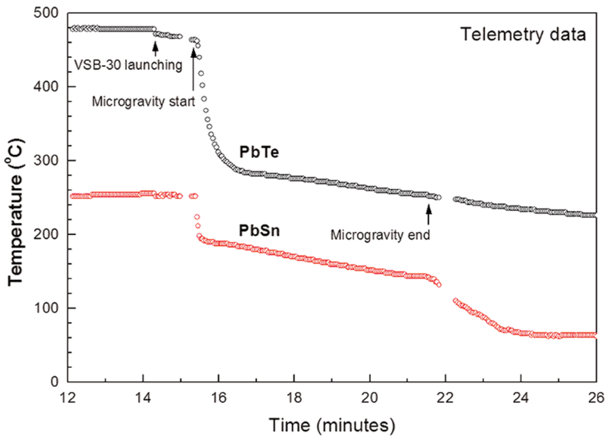

Figure 6. Telemetry data of the solidification furnace thermal cycle during the microgravity flight.

PRELIMINARY EXPERIMENT ANALYSIS

The samples have been analyzed and compared with others solidified at ground, using techniques such as density, X-ray diffraction (XRD), scanning electron microscopy, and X-ray dispersive energy spectroscopy (EDS).

In order to compare the microgravity solidification with a normal gravity one, similar samples have been processed in laboratory with the same thermal gradient, which was shown in Fig. 5, and thermal cycle. The furnace and its control were the same used on the flight itself (Fig. 7), and Fig. 8 compares the thermal cycles used to solidify the PbTe and PbSn eutectic samples on the flight and on the laboratory. The samples solidified at the laboratory are presented in Fig. 9.

Figure 7. Laboratory experimental setup.

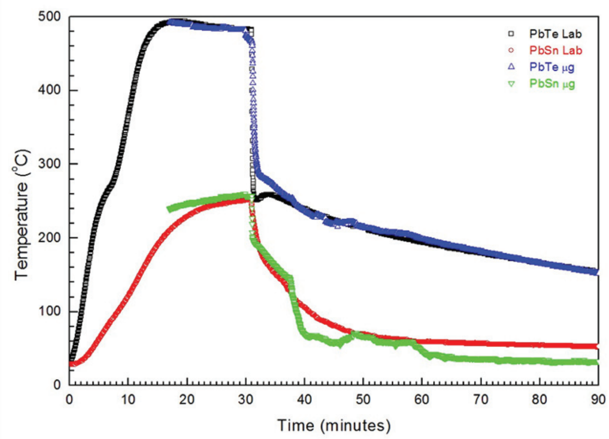

Figure 8. Thermal cycle curves for the microgravity flight and the laboratory experiment.

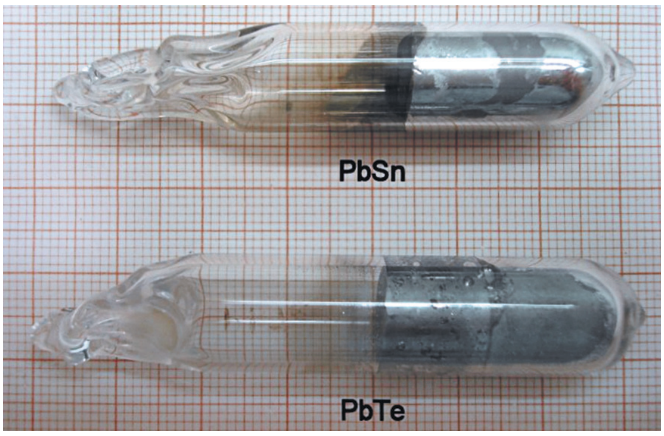

Figure 9. Eutectic PbSn and PbTe samples solidified in quartz ampoules under normal gravity.

CONCLUSIONS

The solidification furnace, provided by LAS / INPE to the Brazilian sounding rocket program, is qualified and ready to be used by other groups that are interested in melting and solidifying alloys in ground and in microgravity environments. The furnace presents an appropriate thermal mass to achieve rapid cooling time by conduction and radiation consistent with the short flight duration, and its electronic and mechanical components performed with precision and reliability during all mission stages. As for the scientific findings, comparing the alloys grown in microgravity and normal gravity, the results will be published elsewhere.

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