# Soldering Alloys in Reduced Gravity

SOLAR

**Anders Svedevall**
Box 812, 981 28 Kiruna, Sweden,
solar.anders.svedevall@gmail.com

**Co-authors**
Adrian Lindqvist
Anneli Prenta
Björn Paulström
Björn Sjödahl
Emil Vincent
Fredrik Persson
Hamoon Shahbazi
Jens Kanje Nordberg
Johan Strandgren
Johanna Åstrand
Maja Nylén
Robert Lindberg
Sara Widbom

**Affiliation: Luleå University of Technology**
Department of Computer Science, Electrical and Space Engineering
Kiruna, Sweden

July 15, 2013

## Abstract

Large funding is required each year for maintaining the International Space Station (ISS) due to need for replacement of components. The cost of this maintenance could be reduced by repairing equipment on site. However, the current method of soldering joints in reduced gravity generates defective connections of components, thus making the repairs insufficient in outer space. The main problem is to solder metals in reduced gravity without obtaining an increase of void fractions, which are inherent due to the lack of buoyant forces on flux and gases. Earlier tests done by NASA, in reduced gravity alone, show an increased amount of void fraction by up to three times as compared to solder created in normal earth gravity. The proposed solution for soldering in reduced gravity is to work in a low pressure environment which enables minimization of void fractions. In vacuum a repairing sequence can be simulated similar to the setting at the ISS but with a reduced pressure. This was tested in an experiment, which was able to melt three samples in vacuum environment and three samples in pressurized environment. To ensure accurate data the solder joints were melted and cooled while in milligravity. This was carried out as the REXUS experiment SOLAR (Soldering Alloys in reduced gravity) in cooperation with several space agencies throughout Europe. The SOLAR experiment was launched with a sounding rocket from Esrange Space Centre, Kiruna (Sweden)in May 2013. After the flight the samples have been analysed at the Kemi-Tornio University of Applied Sciences in Finland by using an X-ray scanner to inspect the void fractions in two dimensions. The result of the reduced gravity soldering have been compared to the similar studies done in the SoRGE and CLEAR projects by NASA, and to the samples created in the pressurized environment of the SOLAR experiment. Suggestions on how to obtain improved soldering joints in space are given based on the final test results.

## Introduction

Human space missions is a challenging task where there is a never ending demand for lower mass and volume solutions. However it's critical for the the mission that there are backup systems and backup instruments which can be used in case of failure. Currently (Jul-2013) astronauts on board the ISS rely on either replacing malfunctioning units altogether or living without them as the crews ability for in situ repairs is limited. After the unit is removed it is returned back to Earth for inspection and reparation[1]. In order to improve the efficiency of mass and volume, rather than replacing an instrument or using multiple systems for redundancy, the instrument can be repaired using backup components. The component that is the source of failure can then be removed and a new component can be soldered onto the same circuit board. In order to do so a soldering procedure suitable for space has to be set up in order to assure space qualified solder joints.

Previous NASA projects SoRGE and CLEAR were conducted on board parabolic flights and the ISS to research low gravity effect on solder joints. The result indicated an increase of voids in solder joint produced in reduced gravity [1] [2]. The voids are produced by a chemical reaction when the flux in the alloy is heated producing oxygen[1]. Other sources such as water vapour from the printed circuit board is also a possible suppliant of of voids.

Voids can also be found in most solder joints created in the standard gravitational pull at ground level on Earth. In order to diminish the voids in the solder joints, vacuum soldering has been used for decades to produce high quality joints for special high demanding applications. The vacuum provides a pressure difference between the voids within the solder and the outside environment which ultimately allows the gas bubbles in the solder to escape giving a uniform density of the alloy.

As vacuum soldering can be used for reducing the number of voids on Earth it is also an interesting aspect to investigate for reduced gravity soldering in order to improve the solder joints enough for space applications. This could resolve the issues experienced in the SoRGE and CLEAR projects.

[1]Soldering in a Reduced Gravity Environment (SoRGE) - John W. Easton, National Center for Space ExplorationResearch

[2]Component-Level Electronic-Assembly Repair (CLEAR) System Architecture - Richard C. Oeftering, Martin A. Bradish, Jeffrey R. Juergens, Michael J. Lewis, and Daniel R. Vrnak Glenn Research Center, Cleveland, Ohio

## Experimental Set-up

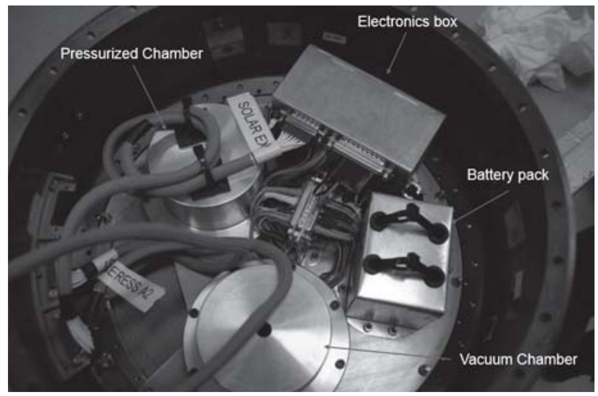


Figure 1: Experimental set-up

To investigate the effect of vacuum on solder joints produced in milligravity an experiment was set up which could be flown on a sounding rocket where the soldering procedure would take less than 30 seconds and in which the samples should be melted and hardened. In order to see whether the result is improved in comparison to specimens produced in a pressurized environment, two sets of samples were produced at the same time where the difference could then be investigated. To compare the result with the result from vacuum soldering on Earth the experiment was run under normal Earth gravity at ground level.

Table 1: Sample environment set-up of the four test scenarios

| **Test scenario** | **Pressure** (Bar) |
|---|---|
| 1G Pressurized | 1 |
| 1G Vacuum | $5\mu$ |
| Low-gravity Pressurized | 1 |
| Low-gravity Vacuum | $10\mu$ |

As the experiment had to be fully autonomous due to the lack of an uplink from the ground station, the melting process was calibrated in advance and carried out by a timer counting from lift off. This was controlled by the electronic circuits shown in Figure 1. In addition the two chambers where the samples are created can be seen. The vacuum chamber has a venting hole in it to allow for a quick transition from pressurized to vacuum environment as the rocket rapidly gains height. The pressurized chamber was sealed using an between the connection between the hat and the base of the chamber. Silicon adhesive was used to seal the feed through of the cables. All electronics and sensors were powered by the service module of the REXUS rocket. However, the resistance wires used for melting the samples were powered by an internal battery pack to accommodate for the large power consumption during the melting phase. Throughout the whole flight the system was recording the temperatures in the chambers and of the resistance wires. In addition pressure sensors were used to monitor the pressure in the vacuum and pressurized chamber. For an overview of the set-up within the experimental chambers please refer to Fig 2. The samples are prepared such that soldering wire is wrapped around a component pin carried out according to a predetermined procedure. The resistance wire is then wrapped around the component pin and soldering wire. Finally the resistance wire is connected to the battery pack through switches controlled by the on board data handling unit. The samples are numbered from one to three where three is closest to the feed through of the cables.

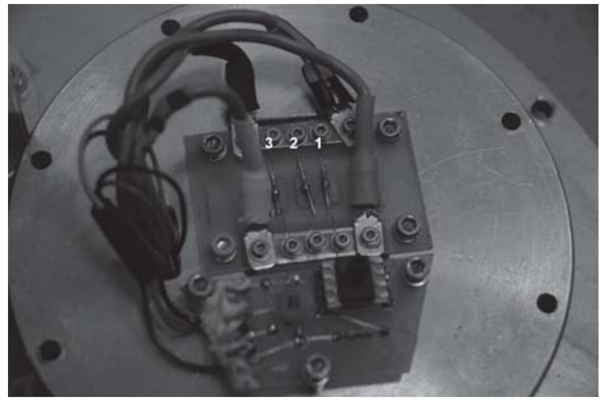


Figure 2: Close up of samples, post flight

## Result

Retrieving the samples post flight, the specimens were subjected to a visual inspection which confirmed that none of the samples were damaged at impact and that all the solder had been melted in flight. They were then taken to the Kemi-Tornio University of Applied Science to be analysed with microscope and X-ray scans. Microscopic images were only taken for sample 2 in each test scenario. The resulting images can be seen in Fig 3

To investigate the voids X-ray scans were done individually for each of the twelve samples. The internal images produced could then be used to estimate the void population.

In order to calculate the void fraction in each specimen the software ImageJ was used to determine for each pixel if it belongs to a void or not. This is then compared to the total area of the void which finally yields an estimate of the void to solder ratio. The result from this can be seen in Tab 2.

Table 2: Void to solder ratio

| **Sample ID** | **1** | **2** | **3** | Average |
|---|---|---|---|---|
| 1G, 1 Bar | 3.2% | 2.4% | 0.9% | 2.2% |
| 1G, 5$\mu$ Bar | 3.6% | 0% | 0.3% | 1.3% |
| mG, 1 Bar | 0.9% | 4.6% | 0.2% | 1.9% |
| mG, 10$\mu$ Bar | 16.4% | 4.8% | 11.9% | 11.0% |

## Discussion

As the data in Tab 2 shows, there is a significantly increased void to solder ratio when, in reduced gravity, soldering is applied in vacuum compared to the test scenario in a pressurized environment. This is the opposite of what was expected. Results of the two reference test scenarios at normal gravity were on average similar to each other and to the results from low-gravity in pressurized environment. The variations in the void to solder ratio between the different samples were quite large, so that it remains unclear if any of these three test

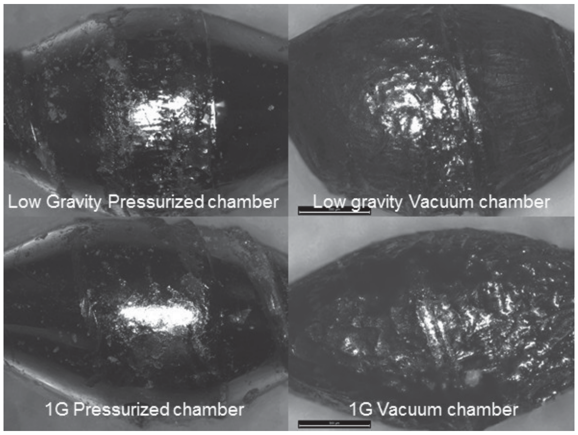


Figure 3: Microscope images of selected samples

scenarios performed better. However, the test scenario with normal gravity in vacuum seems to have produced slightly better solder joints, as expected. The cause of the unexpectedly low quality of solder joints in reduced gravity and vacuum is still not completely understood. One possible reason may be related to the lack of gas around the solder and missing interactions between the liquid lead and the gas in a pressurized environment. At ground level the external force is achieved by gravitation causing the bubbles to be pressed out by buoyancy.

Furthermore the the cooling process of the solder joint proves difficult in a vacuum environment due to lack of convection between the air and the soldering lead. This can be seen in Figure 3 where the solder joints produced in pressure have a smooth shiny surface with a nice wetting angle while the vacuum samples are rough and have a tendency of balling. To control the cooling a gas flow could be implemented into the system where the gas would not only cool the samples but also create an internal flux which could potentially reduce the number of voids.

Qualifying the solder joints for space applications with respect to the void fraction proves difficult as the ECSS documentation lack clear directions for the maximum allowed void population. However judging from the current ECSS documentation the samples produced in pressurized environment in millgravity can be considered acceptable[3].

# Conclusion

The vacuum environment produces the best and worst soldering joints in terms of voids count. Combining vacuum with low gravity clearly produces the largest population of voids where normal gravity combined with vacuum causes the lowest void fraction. When the solder joints were produced in a pressurized environment the gravitation had little to no influence. Due to the low sampling statistics of three samples no conclusions could be drawn if the low-gravity environment produces better or worse solder joints.

# Further Studies

As mentioned in the "Discussion" section a future project aimed at investigating the effect of a gas flow around the melted solder joints is a relevant subject which could possibly further increase the quality of solder joints in space. It would also give a chance to replicate the result of SOLAR using a soldering technique closer related to a practical and applicable soldering procedure for space use.
Furthermore new studies should be conducted looking at pressures between atmospheric and vacuum environment where a critical pressure could be determined giving the maximum quality of the solder joints.

[3] ECSS Secretariat ESA-ESTEC Requirements & Standards Division Noordwijk, The Netherlands

## Acknowledgements

Thanks to Thomas Kuhn and Kjell Lundin who have been our supervisors from Luleå University of Technology and helped us to keep the project going.

Thanks to our contact persons and everyone involved in the REXUS/BEXUS program for the help and for allowing the SOLAR experiment to fly on the REXUS 13 rocket.

Thanks to the sponsors to the REXUS/BEXUS program: ESA, SNSB, SSC and DLR for making the project possible.

Thanks to the SOLAR project sponsors; LTU, LKAB, TRIBOTEC, TÄTRINGEN TEKNISKA AB and IRF for believing in the capability of the SOLAR project and giving financial support.

Thanks to the staff at IRF who's been taking time of their busy schedule to help us with design, building and testing.

Thanks to Petri Ronkainen and Jaana Kauppi at the Kemi-Tornio University of Applied Science for letting us use their lab to analyse the samples and for their expert advice.

Thanks to Jussi Putaala at the University of Oulu for the expert advice and dedication to help us.

Thanks to Esa Vuorinen at Luleå University of Technology for the expert advice and helping us to set up the foundation the project.


## References


[1] - Soldering in a Reduced Gravity Environment (SoRGE) - John W. Easton, National Center for Space ExplorationResearch.

[2] - Component-Level Electronic-Assembly Repair (CLEAR) System Architecture - Richard C. Oeftering, Martin A. Bradish, Jeffrey R. Juergens, Michael J. Lewis, and Daniel R. Vrnak Glenn Research Center, Cleveland, Ohio

[3] - ECSS Secretariat ESA-ESTEC Requirements & Standards Division Noordwijk, The Netherlands