RAPID QUENCH IN AN ELECTROSTATIC LEVITATOR

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Keywords: electrostatic levitation, rapid quench, metastable states, solidification

Abstract

The Electrostatic Levitation (ESL) Laboratory at the NASA Marshall Space Flight Center (MSFC) is a unique facility for investigators studying high-temperature materials. The ESL laboratory's main chamber has been upgraded with the addition of a rapid quench system. This system allows samples to be dropped into a quench vessel that can be filled with a low melting point material, such as a gallium or indium alloy, as a quench medium. Thereby allowing rapid quenching of undercooled liquid metals. Up to eight quench vessels can be loaded into a wheel inside the chamber that is indexed with control software. The system has been tested successfully with samples of zirconium, iron-cobalt alloys, iron-chromium-nickel, titanium-zirconium-nickel alloys, and a silicon-cobalt alloy. This new rapid quench system will allow materials science studies of undercooled materials and new materials development. The system is described and some initial results are presented.

Introduction

The NASA Marshall Space Flight Center (MSFC) Electrostatic Levitation (ESL) Laboratory is a unique facility for investigators studying high-temperature materials. The laboratory has two levitators in which samples can be levitated, heated, melted, undercooled, and resolidified, all without the interference of a container or data-gathering instrument [1].

The ESL laboratory's main levitation chamber has been upgraded with the addition of a rapid quench system. This system allows samples to be dropped into a quench vessel that can be filled with a low melting point material, such as a gallium-indium alloy, as a quench medium. Thereby allowing rapid quenching of undercooled liquid metals.

It has been established that rapid solidification can be achieved by increasing the cooling rate (rapid quenching) or by increasing the undercooling before nucleation [2]. By using a containerless processing technique, such as electrostatic levitation, deep undercooling can be attained. With the rapid quench system added to the MSFC electrostatic levitator, both rapid solidification methods can be done simultaneously.

Quenching in an electromagnetic levitator (EML) has been performed; however, this has involved dropping the sample onto a copper substrate [3]. Similarly, quenching in an electrostatic levitator has also been performed, and in this case, the sample was dropped onto a copper sample launch stem [4].

Quenching on a substrate is less desirable because the cooling occurs from only the contacted surface. It was observed that when the liquid drops onto the copper stem, the heat extraction rates are different at the top and bottom of the sample, which produces different undercooling for the two regions, which causes microstructural transition across different parts of the sample [4].

By submersion quenching into a liquid, the quenching occurs at all surfaces. Quenching with liquid indium-gallium was pioneered by Koseki on steel alloys [5] and surface cooling rates greater than 10^6 W/m^{2}sec were demonstrated. The difference between EML and ESL quenching is that in EML induced fluid flow from the levitation field is both significant and variable across the surface while in ESL the sample is quiescent and the quench conditions are more readily controlled.

Hardware Description

The system is designed so that quench vessels can be raised or lowered using the same stem that is used to launch the samples. Up to 8 quench vessels can be loaded into the quench wheel. An exploded view of the system can be seen in Figure 1, along with the inside of the levitation chamber and the quench hardware.

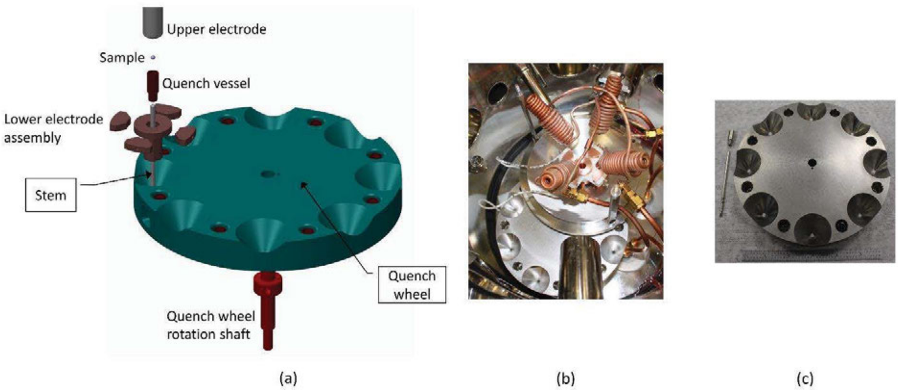

Figure 1. (a) Exploded view schematic of the quench system, (b) inside of the levitation chamber showing the quench wheel, and (c) quench wheel, stem, and quench vessel outside of the chamber.

The wheel is indexed with servo motors that are controlled with LabVIEW software. This allows up to 8 samples to be quenched before having to break vacuum and open the chamber.

The system has been tested successfully on several zirconium, iron-chromium-nickel, and iron-cobalt samples. Future work will be done with other materials and/or different quench mediums.

High-speed video allows observance of the solidification front in sample recalescence. Three high-speed video cameras and two CCD cameras were installed in front of port windows. Two of the high speed cameras and one of the CCD cameras were positioned in front of upper points that have views of the sample from the top. The high-speed cameras available include a Vision Research Phantom V7, an Integrated Design Tools (IDT) Y7, and an IDT Y4.

Results

One of the first rapidly quenched materials in the MSFC ESL lab was an iron-cobalt alloy, Fe50Co50. The sample was melted, and then undercooled to about 30°C under the melting temperature. The quench vessel was then brought up to the quench position and the electrostatic field was removed, causing the sample to fall. Figure 2 shows a still image from the high-speed video taken by the Phantom V7 high-speed camera.

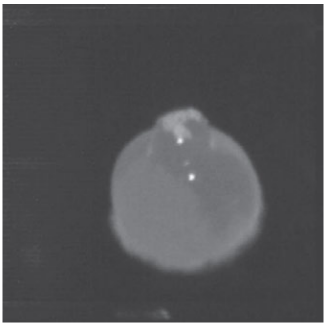

Figure 2. Quench of a Fe50Co50 sample. The video captured the recalescence of the sample as can be seen by the lighter gray region that will eventually engulf the entire sample. The lighter portion at the top of the sample is an oxide.

Sometimes the sample splits into multiple pieces, as can be seen in Figure 3, which shows still images from the high-speed video taken by the IDT Y3 high-speed camera.

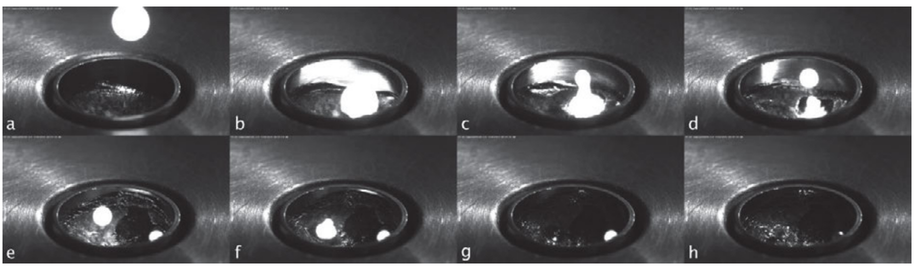

Figure 3. Rapid quench sequence of a Fe50Co50 alloy from (a) start of drop, to (h) end of quench.

The samples were dropped into a gallium-indium alloy (61Ga 25In 13Sn 1Zn), and a post-quench vessel is shown in Figure 4.

Figure 4. Quench vessel filled with a gallium-indium alloy (61Ga 25In 13Sn 1Zn).

Conclusions

Samples of pure zirconium, an iron-cobalt alloy, an iron-chromium-nickel alloy, a titanium-zirconium-nickel alloy, and a silicon-cobalt alloy have been quenched in this facility.

The MSFC electrostatic levitation (ESL) laboratory rapid quench system allows for studies of solidification of a variety of materials. Studies of double recalescence are planned. The quench of a sample during second recalescence will be attempted in order to retain the primary metastable structure.

References

1. J.R. Rogers and M.P. SanSoucie, “Containerless Processing Studies in the MSFC Electrostatic Levitator” (Paper presented at the 50th AIAA Aerospace Sciences Meeting, Nashville, TN, 2012).
2. M.C. Flemings and Y. Shiohara, “Solidification of Undercooled Metals,” *Materials Science and Engineering*, 65 (1984), 157-170.
3. R. Herman et. al., “Metastable phase formation in undercooled Fe-Co melts,” *Materials Science and Engineering: A*, 375-377 (2004), 507-511.
4. G.W. Lee, A.K. Gangopadhyay, and K.F. Kelton, “Phase diagram studies of Ti–Zr–Ni alloys containing less than 40 at.% Ni and estimated critical cooling rate for icosahedral quasicrystal formation from the liquid,” *Acta Materialia*, 59 (2011), 4964-4973.
5. T. Koseki, M.C. Flemings, “Solidification of Undercooled Fe-Cr-Ni Alloys III: Phase Selection in Chilling”, *Metallurgical and Materials Transactions A*, 28A (11) (1997), 2385-2395.