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DESCRIPTIONS OF SPACE PROCESSING APPLICATIONS ROCKET (SPAR) EXPERIMENTS

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George C. Marshall Space Flight Center
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FOREWORD

The Space Processing Applications Rocket (SPAR) program was initiated in 1974 to provide multiple opportunities for low-gravity experimentation during the interim between the Skylab and Apollo-Soyuz missions and the advent of the Space Shuttle. The SPAR vehicle consists of a Black Brant rocket with an optional Nike booster. The system can provide up to 5 min of free-fall time for a payload of 500 to 700 lb.

The short low-gravity time available and the harsh launch environment restrict the types of experiments that can be conducted with the SPAR system; however, a large number of investigations of low-gravity phenomena have been performed, and the program has provided valuable experience for developing experiments and apparatus for research in low-gravity processes.

This document contains a summary of all of the SPAR experiments, including those flown on previous SPAR flights as well as those under development for future flights. The experiments were selected by external peer review from proposals submitted in response to Announcements of Opportunities (AO's) issued in 1974, 1976, and 1977.

To date, five SPAR vehicles have been launched. Four additional flights are planned. The experiment descriptions are grouped according to those already flown, those that have reached sufficient maturity to be accepted for flight in the next two SPAR vehicles currently being integrated, and those experiments still in a state of development. When a sufficient number of these experiments become flight-ready as determined by a Flight Readiness Review, they will be assigned to a specific flight and integration will begin.

This document will be updated periodically as new results become available. Either the Principal Investigator or the Marshall Space Flight Center (MSFC) Science Advisor who is cognizant of the experiment may be contacted for additional information.

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PART I

COMPLETED EXPERIMENTS

SPACE SOLIDIFICATION OF Pb-Sb EUTECTIC

SPAR Experiment 74-5

Principal Investigator: Robert B. Pond, Sr.
Marvalaud, Inc.

Co-Investigators: John W. Winter, Jr., Stephen L. Van Doren, and David A. Shifler
Marvalaud, Inc.

Science Advisor: Don Reiss
ES74, MSFC

Objective

The objective of this experiment was to investigate the possibility of obtaining a complete utectic structure in 88.8 Pb-11.2 Sb in microgravity.

Rationale

Pb-Sb eutectic is of interest because it should be superplastic, allowing it to undergo tensile strains of 100 percent before rupturing. This would allow manufacturing processes not possible with conventional materials. Also, superplastics would be useful as shaped charge liners which enhance the penetrating power of shaped charges. Shaped charges are used extensively in both commercial and military applications. One of the problems encountered in studying this material is that if nucleation of either of the primary phases occurs, the density difference of the two phases results in segregation. This segregation would be eliminated in microgravity.

Approach

Three Pb-Sb alloys were prepared: a eutectic alloy, a hypereutectic alloy, and a hypoeutectic alloy. These were melted and rapidly solidified during the low-gravity phase of the flight. Similar samples were instrumented with thermocouples, melted, and quenched on the ground using a number of different quench methods. After solidification the samples were metallographically examined and subjected to mechanical tests.

Results

The eutectic alloy was flown on SPAR I. This sample had rounded edges on both ends, indicating that it had solidified in a microgravity environment. The hypereutectic and hypoeutectic alloys were flown on SPAR II. These samples had sharp corners on one end and cavities in the centers. These have not been explained. The presence of these cavities severely limited the mechanical testing of the specimens. Both the ground-based samples and the flight samples contained primary Sb and primary Pb crystallization products, indicating a shift in the eutectic point due to supercooling. There was no discernible difference between the mechanical properties of the flight samples and those of the ground-based samples.

Publications

1. SPAR I Final Report. NASA TM X-3458, December 1976.

2. SPAR II Final Report. NASA TM X-78125, November 1977.

FEASIBILITY OF PRODUCING CLOSED-CELL METAL FOAMS IN A ZERO-GRAVITY ENVIRONMENT FROM SPUTTER-DEPOSITED, INERT GAS-BEARING METALS AND ALLOYS

SPAR Experiment 74-10

Principal Investigators: J. W. Patten and
E. N. Greenwell
Battelle-Northwest Laboratories

Science Advisor: R. Ruff
ES74, MSFC

Objective

The objective of this experiment was to produce metal foam materials from sputtered metal deposits and to evaluate the effects of gas concentration, melt temperature, and time at melt temperature on foam structure and foaming kinetics.

Rationale

Metal foams are desirable because of their characteristics such as high stiffness-to-density ratio, high damping capability, high impact resistance, and low thermal conductivity. They could be used as structural materials where high strength and low weight are required. When a sample of metal with trapped gas is melted, density differences cause separation of the gas and molten metal so that a uniform metal foam does not form. In low gravity there would be no density difference driving force to induce separation of the gas from the metal matrix.

Approach

Samples consisted of sputtered deposits of aluminum and argon. Three gas concentrations were subjected to three different times above the melting point and then water-quenched. The samples were recovered and subjected to metallographic examination. The results were compared to ground-based test results.

Results

Gas content variation and time at temperature did not have a great influence on the microstructure of thin specimens. In thick samples, bubble coarsening and increases in void volume fraction were observed with increasing time at temperature. Trends were observed toward fewer cells/unit volume, less scatter in the number of cells/unit volume, and larger median cell size in space-processed samples than in ground-based samples. No trends were observed in mean cell size or scatter in mean cell size. The formation of oxide layers on sample surfaces produced irregular mechanical restraint to the expanding foam. This severely limited the amount of information that could be obtained from analysis of the samples.

Publications

1. SPAR I Final Report. NASA TM X-3458, December 1976.

2. SPAR II Final Report. NASA TM X-78125, November 1977.

3. Patten, J. W. and Greenwell, E. N.: Closed-Cell Foams Produced from Sputter-Deposited Aluminum--Experiments in Earth and Space. AIAA Paper 77-193, January 1977.

CASTING DISPERSION-STRENGTHENED COMPOSITES AT ZERO GRAVITY

SPAR Experiment 74-13

Principal Investigators: L. Raymond and C. Y. Ang
Th· ·· ··pace Corporation

Science Advisor: L. L. Lacy
ES74, MSFC

Objective

The purpose of this SPAR experiment was to gain an understanding of low-gravity effects on the dispersion of particles in a metal matrix and to develop techniques of casting in space dispersion-strengthened metal composites that are difficult to achieve on Earth because of large differences in density of the constituents.

Rationale

The strengthening of a metal, especially at elevated temperatures by the dispersion of fine particles in the matrix, is a well-known phenomenon. It is generally believed that fine particles less than 0.1 μm in size and interparticle spacing of approximately 0.5 μm will lead to optimum strengthening with a density of dispersoids from 1 to 10 volume percent. Several studies have shown that strengthening can also be achieved with dispersoid sizes as large as 5 μm. The strengthening of such composite systems will depend upon the technique for introducing or forming the dispersed particles and upon the uniformity of the dispersion. Agglomeration and sedimentation of the dispersed particles will thus have an important influence on the strength of the cast composite.

Approach

Two experiments were performed. The first experiment on SPAR I melted and resolidified a compacted powder sample of Mg and ThO_2 particle (2 v/o ThO_2). The second experiment on SPAR II used compacted powder samples of Mg, Th, and MgO which formed ThO_2 particles by the gettering reaction $Th + 2MgO \rightarrow 2Mg + ThO_2$. By comparing low-gravity and one-gravity samples processed under identical conditions, a better understanding was obtained of how gravity-induced sedimentation influences the strengthening of Mg.

Results

SPAR I: The low-gravity flight sample had no detectable internal porosity; whereas the one-gravity sample retained a large shrinkage cavity and contained many small internal voids. This phenomenon is considered a beneficial effect of low gravity when a liquid does not wet the melt. The nonuniformly distributed layers of dispersion-depleted areas in all the one-gravity samples were considered as gravity-induced sedimentation interrupted and agitated by convective currents and gas motions. The ThO_2 particles in the low-gravity sample were more dispersed than in the one-gravity sample. The large dispersion-depleted areas in the low-gravity sample were probably caused by a thermoacoustic effect during the rapid heat-up resulting in expanded gas pockets in the melt where it entered the low-gravity soak stage.

SPAR II: The low-gravity melting and solidification of particle-dispersed metal matrices in a gas-filled encapsulated system is feasible and will produce sound ingots with no internal pores. The gettering-dispersion mechanism can be utilized to cast composites that are difficult to cast on Earth. On the basis of microhardness measurements, the low-gravity sample is much more uniform in properties than the one-gravity counterpart. The average hardness of the low-gravity sample is twice that of pure Mg and is 30 percent greater than the one-gravity sample and the commercial Mg-Th-Zr (HK31A) alloy.

Publications

1. SPAR I Final Report. NASA TM X-[illegible] December 1976.
2. SPAR II Final Report. NASA TM X-78125, November 1977.

UNIFORM DISPERSIONS BY CRYSTALLIZATION PROCESSING

SPAR Experiment 74-15

Principal Investigator:	Donald R. Uhlmann Massachusetts Institute of Technology
Co-Investigator:	Bennet Joiner Massachusetts Institute of Technology
Science Advisor:	Robert J. Naumann ES71, MSFC

Objective

The objective of this experiment was to develop improved understanding of the interactions between second-phase particles and an advancing crystal-liquid interface and to develop a criterion for rejection/incorporation in terms of solidification rates for various particle characteristics.

Rationale

One of the attractive prospects for materials processing in weightlessness is the possibility of solidifying melts with uniform dispersions of second-phase particles. Such composites may have applications as solid-state electrolytes with enhanced ionic conductions, oxide dispersion-hardened alloys for use as turbine blades, etc. It is known that dispersion forces between the molecules in the melt tend to push particles ahead of the solidification front; whereas drag forces tend to retard their motion. A critical growth velocity exists below which particles are pushed ahead of the solidification front and above which they are incorporated. A theory has been developed to predict the critical velocity as a function of particle properties, such as size, density, thermal conductivity, etc. The absence of gravitational sedimentation allows an experimental check to be made on the theory without extraneous frictional forces from the particles moving along the wall of the container.

Approach

The experiment consisted of seven cuvettes containing camphor (which has an entropy of fusion similar to metals) and various size and composition particles. During the low-gravity coast these cuvettes were melted back and directionally resolidified. One cuvette was photographed during the process to establish the growth rate.

Results

The experiment was initially attempted on SPAR I using zinc particles in naphthalene that was partially melted at launch and solidified during the low-gravity coast. The spin-up and spin-down associated with the launch resulted in a concentration of all the particles along the axis of the cuvette. Because of this pile-up of particles, no particle pushing could be observed.

The experiment failed on SPAR IV because of breakage of the cuvette that was photographed and because of the failure of a relay to remove power before reentry. There is evidence that the sample was reprocessed in a one-gravity environment. A reflight on SPAR V apparently returned data, which is currently being analyzed.

Publications

1. SPAR I Final Report. NASA TM X-3458, December 1976.

2. Uhlmann, D. R.; Aubourg, P. A.; and Joiner, B.: "Multiphase Dispersions by Crystallization Processing." XXI COSPAR Meeting, Innsbruck, Austria, 1978 (to be published in the Proceedings of COSPAR, Pergamon Press).

LIQUID MIXING EXPERIMENTS

SPAR Experiments 74-18, 18/2, and 18/3

Principal Investigator: Charles F. Schafer
ES84, MSFC

Co-Investigator: George H. Fichtl
ES84, MSFC

Objective

A primary objective of these experiments was to characterize the sounding rocket environment with respect to residual accelerations which could lead to gravity-like body forces in liquid systems. In addition, the experiments should emphasize the necessity for carefully planning low-gravity experiments with respect to possible motions at low acceleration levels.

Approach

Metal samples were constructed in the form of cylinders with half of each sample being composed of pure indium and the other half being an In (80 wt%) and Pb (20 wt%) alloy (the samples were axially symmetric). These were enclosed in aluminum cartridges and placed in heater assemblies, so that each sample was either parallel or perpendicular to a radius from the rocket payload axis. This insured that the density gradient in the samples was either parallel or perpendicular to the effective residual accelerations, assuming that they would arise mainly due to residual rotation (spin) of the payload.

The samples were melted after entry into the low-gravity portion of the payload trajectory and were resolidified before leaving low gravity.

Results

Samples oriented such that the denser material was inward (closer to the payload longitudinal axis) experienced flow over nearly the length of the sample. This flow was predictable using analysis which provided a Rayleigh number as a flow predictor, when the residual acceleration levels were taken to be on the order of 10^{-6} g. In addition, linear analysis indicated that perturbation growth times for these cases were on the order of the experiment duration.

Samples with their density gradients perpendicular to the radius vector (from the payload longitudinal axis) experienced a slight deformation of the interface. This region was within the predicted diffusion distance of approximately 1 mm from the original interface. Estimates of flow based on a related model system yield an upper bound on residual accelerations of approximately 10^{-5} g.

Comments

Residual low-level accelerations (10^{-6} to 10^{-5} g) exist on the SPAR payload. These can lead to appreciable flows in liquids containing large density gradients in the few minutes of experiment time. Relatively simple analyses can be performed which can yield order of magnitude estimates of these flow effects. Also, proper orientation of samples can minimize (or maximize) these effects.

Publications

1. Schafer, Charles F. and Fichtl, George H.: SPAR I Liquid Mixing Experiment. AIAA Journal, Vol. 16, No. 5, May 1978, pp. 425–430.

2. Schafer, Charles F.: Liquid Mixing Experiment. SPAR I Final Report, NASA TM X-3458, December 1976, pp. IV-1 to IV-37.

3. Schafer, Charles F. and Fichtl, George H.: Liquid Mixing (Experiment 74-18/2, 3). SPAR III Final Report, NASA TM-78137, January 1978, pp. III-1 to III-16.

DENDRITE REMELTING AND MACROSEGREGATION IN CASTINGS

SPAR Experiments 74-21/2 and 21/3

Principal Investigator: M. H. Johnston
EH22, MSFC

Co-Investigator: C. S. Griner
EE41, MSFC

Science Advisor: Richard Parr
EH22, MSFC

Objective

The objective of this experiment was to investigate the effect of convection on the microstructure of metallic castings. Of particular interest were the mechanisms of dendrite multiplication and transport, secondary nucleation, and freckling.

Rationale

The mechanisms involved in the solidification of castings are quite complex. Both thermal and solutal convection act to redistribute solute, break off dendrite tips, and transport these fragments throughout the melt, forming new nucleation sites. The situation is vastly different in low gravity where the primary driving force for these convective flows no longer operates. One way to investigate the effects of gravity-driven convection is to compare two systems that are identical except for the presence of gravity. Also, this approach is useful for assessing the importance of nongravity forces (if any) that are often masked by the more dominant gravity-driven forces.

Approach

A transparent metal model system, NH_4Cl and H_2O, was used to study nucleation and growth processes, dendrite multiplication and transport, and grain morphology. Thermoelectric devices along the cuvette walls provided the cooling to produce solidification. Data were recorded by a 35 mm camera at 1 frame per second.

Results

A cuvette with cooling from opposite walls was flown on SPAR I and returned excellent photographs, which have been made into movies comparing the one-gravity and zero-gravity processes.

Two cuvettes were flown on SPAR II, one cooled from the bottom only and the other cooled from three sides. The solution failed to solidify. The experiment was repeated with modified apparatus on SPAR V. Solidification occurred and useful photographs were returned. Analysis is in progress.

Publications

1. Johnston, M. H. and Griner, C. S.: Compositional Variations in the Undercooled Pb-Sn Eutectic Solidified at Various Acceleration Levels. Scripta Metallurgica, Vol. II, 1977, p. 253.

2. Johnston, M. H. and Griner, C. S.: The Direction Observation of Solidification as a Function of Gravity Level. Met. Trans., Vol. 8A, 1977, p. 77.

3. Johnston, M. H.; Griner, C. S.; and Grodzka, P. G.: Convection Analysis of the Dendrite Remelting Rocket Experiment. AIAA Journal, Vol. 16, 1978, p. 417.

4. Grodzka, P. G.; Pond, J. E.; and Spradley, L. W.: Thermal and Convection Analysis of the Dendrite Remelting Rocket Experiment, 74-21. LMSC-HREC TR D496847, Lockheed Huntsville Research and Engineering Center, May 1976.

AGGLOMERATION IN IMMISCIBLE LIQUIDS AT LOW GRAVITY

SPAR Experiment 74-30

Principal Investigator: S. Gelles
Gelles Associates

Science Advisor: L. L. Lacy
ES74, MSFC

Objective

The objective of this experiment was to determine the effect of composition and cooling rate, and the presence or absence of gravitational forces on the structure of liquid-phase immiscible alloys. The aluminum-indium immiscible system was used.

Rationale

Liquid-phase immiscible alloys are a useful class of materials whose application may be increased by space processing. Low-gravity processing of these alloys could lead to unique microstructures and metastable phases not obtainable in bulk on Earth. This experiment should lead to the determination of quantitative relations between the alloy structure and processing conditions, including gravitational forces.

Approach

Pure indium and pure aluminum starting materials were enclosed in an alumina crucible cartridge. Four cartridges were provided that contained varying compositions of pure aluminum and indium. Prior to launch, the samples were heated to 900°C and held at this temperature until the low-gravity portion of the flight was reached. The cartridges were then cooled through the immiscibility gap and the alloys solidified in low gravity to prevent the sedimentation of the more dense phase. After recovery, the samples were processed to reveal their microstructure.

Results

The experiment was flown on SPAR II. The recovered sample showed almost complete separation of the Al and In phases instead of the anticipated fine dispersion. It is not clear whether the material separated because of nongravity-driven flows during solidification or whether the material was never completely mixed. Subsequent tests showed that the initial soak time was not sufficient to assure adequate mixing. The experiment was reflown on SPAR V with a 16-hour preflight soak above the consolute temperature. The sample was successfully recovered and is presently being analyzed.

Publications

1. Gelles, S. H. and Markworth, A. J.: Microgravity Studies in the Liquid Phase Immiscible System, Al-In. AIAA Paper 77-122, January 1977.

2. Gelles, S. H.; Collings, E. W.; and Abbott, W. H.: Analytical Study of Space Processing of Immiscible Materials for Superconductors and Electrical Contacts. NASA CR-150156, January 1977.

3. Markworth, A. J.; Oldfield, W.; Duga, J.; and Gelles, S. H.: Investigation of Immiscible Systems and Potential Applications. NASA CR-120667, April 1975.

4. Moak, D. P.; Griesenauer, N. M.; and Gelles, S. H.: Undercooling of Materials during Solidification in Space. NASA CR-120750, April 1975.

5. SPAR II Final Report. NASA TM X-78125, November 1977.

THE INTERACTION OF BUBBLES WITH SOLIDIFICATION INTERFACES

SPAR Experiment 74-36

Principal Investigator: John M. Papazian
Grumman Aerospace Corporation

Science Advisor: Ilmars Dalins
ES71, MSFC

Objective

The objective of this experiment was to observe the interaction of the solidification interface with bubbles and to observe the migration of bubbles in a thermal gradient.

Rationale

In the absence of buoyant forces, the presence of bubbles may interfere with the processing of materials in low gravity. Also, these interactions are of fundamental interest in the study of dispersive forces and of the effect of thermal Marangoni (surface tension) convection. This experiment is designed to investigate methods for control of bubbles in low-gravity processes.

Approach

A special apparatus consisting of three ampoules containing CBr_4 saturated with various gases was designed and constructed. Heaters held the CBr_4 above the solidification temperature until the low-gravity portion of the flight, at which time one end was allowed to cool. Bubbles nucleated during the solidification process and were observed photographically.

Results

The experiment was flown on SPAR I. The solidification was dendritic, which tended to trap the bubbles. Bubbles nucleating ahead of the front did not appear to move in the thermal gradient. The experiment was flown again on SPAR III with a higher thermal gradient (20 K/cm). Similar results were obtained.

It has been suggested that trace impurities in the CBr_4 alter the surface tension dependence with temperature and prevent the thermal Marangoni convection from producing a net driving force in a thermal gradient. It is also possible that the bubbles reside on the walls of the container, which prevents their motion.

Publications

1. SPAR I Final Report. NASA TM X-3458, December 1976.

2. SPAR III Final Report. NASA TM X-78137, January 1978.

3. Papazian, J. M.: The Interaction of Bubbles with Solidification Interfaces. AIAA Paper 77-194, January 1977.

4. Papazian, J. M. and Wilcox, W. R.: Thermal Migration of Bubbles and Their Interactions with Solidification Interfaces. NASA CR-144304, April 1976.

5. Papazian, J. M. and Larson, D. J.: Research on Metal Solidification in Zero-g State. NASA CR-144013, July 1975.

CONTAINED POLYCRYSTALLINE SOLIDIFICATION IN LOW GRAVITY

SPAR Experiment 74-37

Principal Investigator: John M. Papazian
Grumman Aerospace Corporation

Co-Investigator: Theodoulos Z. Kattamis
University of Connecticut

Science Advisor: Ilmars Dalins
ES71, MSFC

Objective

The objective of this experiment was to evaluate and understand the role of gravity-driven convection on the cast microstructures during solidification by examining the columnar-to-equiaxed transition in a cylindrical configuration with radial heat flow.

Rationale

Cylindrical castings generally have a columnar grain structure oriented in the radial direction near the surface and an equiaxed grain structure in the interior. The mechanism for this transition has been the subject of several speculative theories. By performing the experiment in one-gravity and zero-gravity environments, it is hoped to elucidate the role of gravity-driven convection in the formation of the equiaxed zone.

Approach

A transparent metal model system, NH_4Cl and H_2O, was chosen to allow the process to be studied photographically in real time. Four semicircular cells were used, permitting two different orientations of two cells which contained different concentrations of NH_4Cl. Cooling was accomplished by a flow of freon gas around the circumference of the cells. The solidification process was recorded on the ground and during the coast phase of the rocket.

Results

Excellent photographs of dendrites breaking and the fragments circulating into the interior to nucleate the equiaxed structure have been obtained at one gravity. A flight on SPAR IV failed because of a cooling system blockage. Another flight on SPAR V returned useful data that are currently being analyzed.

CONTAINERLESS PROCESSING OF BERYLLIUM

SPAR Experiment 74-48

Principal Investigator: G. Wouch
General Electric Company

Co-Investigators: George Keith and Tom Frost
General Electric Company

Norman Pinto
Kawecki Berylco Industries, Inc.

Science Advisor: W. A. Oran
ES72, MSFC

Objective

The objective of this experiment was to prepare cast beryllium with enhanced service properties through utilization of dispersed oxide, BeO, as a grain refining agent and to improve the microstructure of cast beryllium.

Rationale

Obtaining a finer grained casting of beryllium with uniform dispersion of oxide throughout would produce cast beryllium with enhanced room temperature ductility, coupled with high-temperature strength. On Earth the BeO tends to agglomerate and separate.

Approach

A sample of KBI-HIP-50 beryllium alloy (1.5% BeO by weight) was positioned, melted, and solidified in an electromagnetic system at 18 psig argon atmosphere. To the extent possible, similar samples were levitated, melted, and solidified under similar conditions on Earth. The analysis of the experiment essentially compared the material processed under zero gravity and one gravity.

Results

A uniform dispersion of BeO was obtained with the sample melted/solidified in zero gravity. This uniform dispersion cannot be obtained under terrestrial conditions. The final material was coarse grained and not fine grained.

Publications

SPAR III Final Report. NASA TM X-78137, January 1978.

PREPARATION OF A SPECIAL ALLOY UNDER ZERO GRAVITY FOR MAGNETIC HARD SUPERCONDUCTORS

SPAR Experiment 74-63

Principal Investigators: Werner Heye and Michael Klemm
Technical University
Clausthal, West Germany

Science Advisor: R. Ruff
ES74, MSFC

Objective

The objective of this experiment was to produce a second- or third-order superconductor from a mixture of first-order superconductor (lead) and a normal electrical conductor (silver).

Rationale

The known second-order superconductors are distinguished primarily by the almost undeformable state, e.g., intermetallic compounds such as Nb_3Sn. For manufacturing purposes, a ductile material is practically necessary. One approach is to search for an alloy in which both phases (first-order superconductive and normal conductive) exist parallel within dimensions less than the electron free path length for cross direction of the electrical flux. This necessitates that the alloy contain thin fibers or small particles with diameters or thicknesses of approximately 100 Å.

Approach

Theoretically, a mixture of lead and silver particles, after deformation, should be a second-order superconductor. However, because the silver particles are much stronger than the lead particles, only the lead deforms during a two-stage extension and drawing process. BaO particles can be used to strengthen the lead by strain hardening. Even so, standard techniques of sintering do not result in the desired properties because of pores and cracks. It was proposed to melt the two materials in zero gravity to avoid the liquid phase segregation which occurs on Earth.

Results

A specimen of Pb-Ag-BaO was melted and solidified in zero gravity on SPAR I. A comparison sample was melted on Earth during a thermal test. Both specimens were extended in the same manner. No metallurgical differences were visible. However, the flight specimen, but not the control specimen, did evidence the desired splitting of the critical magnetic field into two components. The postulated explanation is that the flight sample had some diffusion of the Ag into the Pb which resulted in a large number of very small Ag particles that were not visible by light microscopy.

Publications

1. SPAR I Final Report. NASA TM X-3458, December 1976.

2. Heye, W. and Klemm, M.: ESA Material Sciences in Space (N 77-14066 05-12).

PART II

EXPERIMENTS SELECTED FOR SPAR VI AND SPAR VII

GLASS FORMATION

SPAR Experiment 74-42

Principal Investigator: Ralph Happe
Rockwell International, Space Division

Science Advisor: Jerry Johnson
ES74, MSFC

Objective

The objective of this experiment is to form glasses of unique composition by use of containerless processing to avoid nucleation and crucible contamination.

Rationale

It is desirable to explore the possibility that certain oxides or selected materials which do not readily form glasses in the Earth environment might be induced to do so in space. The projected combination of new and useful optical properties for such glasses appears attractive in developing advanced optical systems.

The space environment will be unique in providing microgravity and containerless melting capability. This uniqueness should substantially increase the probability of making glasses from substances which to date occur only in a crystalline condition.

Containerless melting eliminates extraneous contamination by crucible wall material and possible sites for heterogeneous nucleation during cooling. Higher melting point and corrosive melt materials can also be investigated using this technique.

Approach

An acoustic single-axis levitator will be employed to position a small specimen (6 to 7 mm) in a furnace. After the specimen is melted, the furnace will be turned off and the molten sphere allowed to cool in an unperturbed environment. After cooling, the processed sample will be safely retained for its return trip to Earth. A movie camera will record the complete processing procedure.

Expected Results

To maximize the probability of glass formation and check out extraneous parameters for the first flight experiment, a three-constituent system of gallia, calcia, and silica will be used. The silica will slightly degrade the expected optical property projections but will enhance glass formation.

If all goes well, a binary gallia/calcia composition will then be processed on the second flight and its optical properties measured upon return to Earth.

Status

An Intersonics, Inc., single-axis acoustic levitation furnace has been flight qualified, and the experiment has been accepted for SPAR VII.

EPITAXIAL GROWTH OF SINGLE-CRYSTAL FILMS

SPAR Experiment 74-45

Principal Investigator: M. David Lind
Rockwell International Science Center

Co-Investigator: Roger L. Kores
ES74, MSFC

Objective

The objective of this experiment is to grow an epitaxial film of gallium arsenide by liquid-phase epitaxy in low gravity and to compare it with films grown in normal gravity.

Rationale

Convection and sedimentation affect the transfer of material and heat in liquid-phase epitaxy systems and, unless somehow suppressed, result in undesirable nonuniformities in growth rates and in the distributions of dopants or impurities, accompanied by strains and structural defects. Complete suppression of convection and sedimentation, with independent control of system dimensions and temperature gradients, can be achieved only in low gravity.

Approach

Gallium arsenide substrate wafers mounted in a graphite slider mechanism are moved by means of a piston to bring them into contact with a high temperature (~720°C) saturated solution of gallium arsenide in liquid gallium in a tubular resistance-heated furnace. After a growth period of 1 minute, the growth is terminated by retracting the slider.

Expected Results

Films with improved compositional uniformity, less strain, and fewer structural defects are expected. Conventional techniques for characterizing semiconductor materials will be used to examine the space-grown films and compare them to films grown in normal gravity.

Status

The experiment was flown on SPAR III and failed because of a broken linkage in the slider mechanism. The system has been modified and accepted for flight on SPAR VI.

CONTAINERLESS PROCESSING TECHNOLOGY

SPAR Experiment 76-20

Principal Investigator: T. G. Wang
Jet Propulsion Laboratory

Co-Investigators: D. D. Elleman and M. M. Saffren
Jet Propulsion Laboratory

Science Advisor: W. Oran
ES72, MSFC

Objective

The general objective is to study basic technology related to the containerless processing of materials in an acoustic chamber in space. The specific initial objectives are:

1. Determine the positioning capability of the acoustic system.

2. Determine the perturbation of drop shape oscillation due to gravity-jitter induced center of mass motion.

3. Determine the rotational capability of the acoustic chamber.

4. Determine the perturbation of drop rotation due to gravity jitter.

Rationale

In containerless processing, most of the processes are carried out in a liquid-melt state. The aim of these experiments is to gain a better understanding of the physics of liquid melts and the capabilities of manipulating liquid melts in a long-term, zero-gravity environment, thus aiding in the future design of a practical system for space processing. The effort will initially study the stability and manipulability of liquid drops at room temperature as a useful and cost-effective step in the development of a high-temperature, three-axis acoustic positioning system.

Approach

The experiment will use the three-axis acoustic positioning system already developed by the Jet Propulsion Laboratory. A liquid drop will be deployed approximately 100 seconds after lift-off. The drop will be driven into its normal mode of oscillation by frequency modulating the acoustic drivers. The oscillations will be allowed to decay, and the drop will be spun up by phase shifting the output of two of the drivers. The rotation will be allowed to freely decay. Data will be taken with a cine camera at 64 frames per second.

Expected Results

The general expected result of these studies is to further the knowledge of containerless processing techniques in space, especially in regard to the handling of liquid materials. Specifically, the experiment will:

1. Determine the positioning capability of the acoustic chamber by measuring the time required for a positioned liquid drop to approach its quiescent state.

2. Obtain data on the damping constant of drop oscillation.

3. Obtain data on the damping constant of center-of-mass motion of drop.

4. Determine the coupling between oscillation and center-of-mass motion of drop.

Status

The apparatus was flown on SPAR IV. A liquid drop was successfully deployed and captured in the acoustic field. An electronic failure terminated the experiment before the remaining tests could be performed. The experiment has been accepted for flight on SPAR VI and SPAR VII.

DIRECTIONAL SOLIDIFICATION OF MAGNETIC COMPOSITES

SPAR Experiment 76-22

Principal Investigator: D. Larson, Jr.
Grumman Aerospace Corporation

Co-Investigator: W. R. Wilcox
Clarkson College

Science Advisor: J. McClure
EH21, MSFC

Objective

The objective of this experiment is to investigate the microstructure and magnetic properties of MnBi/Bi at different growth rates to determine what role convection plays in the directional solidification of this system.

Rationale

An unusually high coercive strength phase at low temperatures was discovered in the MnBi/Bi eutectic material directionally solidified on Apollo-Soyuz Test Project (ASTP) Experiment MA-070. Although material processed in the laboratory has exhibited this high coercive phase at low temperatures, the values attained by the MA-070 samples have never been duplicated for the same growth conditions. This experiment will utilize the SPAR opportunity to provide additional data at different growth rates to further investigate the effect. In addition, these data will provide design information to make later Spacelab experiments more effective.

Approach

MnBi samples are loaded into quartz tubes 6 mm in diameter by 30 cm long. The Automatic Directional Solidification Furnace (ADSF) built by General Electric will process four samples during the low-gravity duration of SPAR by moving a heater and chill-block along the sample at a predetermined rate. Thermocouples imbedded in the sample record the thermal history and growth rate. Ambient temperature magnetic characterization is performed at Grumman Aerospace Corporation, but the 1-joule magnet at the Bitter National Laboratory is required to measure the high coercive phase at low temperatures.

Expected Results

A matrix of values of composition, growth rate, and gradient has been defined to systematically investigate the effect of convection on the directional solidification of the Mn/Bi system. The SPAR experiment will return eight samples at two different growth rates.

Status

The ADSF has passed flight qualification, and the experiment has been selected for flight on SPAR VI and SPAR VII.

Publications

1. Larson, D. J. and Pirich, R. G.: Low-G Bridgman Growth of Eutectic MuBi/Bi Magnetic Composites. Fourth American Conference on Crystal Growth, NBS, Gaithersburg, Maryland, July 1978.

2. Pirich, R. G.; Larson, D. J.; and Busch, G.: Magnetic and Metallurgical Properties of Directional Solidified Eutectic MnBi/Bi Composites: The Effect of Near 0-g and Anneal. 24th Conference on Magnetic Materials, Cleveland, Ohio, November 1978. Also accepted for publication in J. Appl. Physics.

3. Pirich, R. G.; Larson, D. J.; and Busch, G.: High Rate Directional Solidification of MnBi/Bi Magnetic Composites. Conference on Insitu Composites — III, Boston, Massachusetts, December 1978.

ALLOY CASTING

SPAR Experiment 76-36

Principal Investigator: M. H. Johnston
EH22, MSFC

Science Advisor: Richard Parr
EH22, MSFC

Objective

The objective of this experiment is to investigate the factors affecting nucleation and growth in normal coasting processes of metals as influenced by gravity-induced convection.

Rationale

This experiment is designed to investigate the similarities between metal model solidification results carried out in earlier SPAR flights (Experiment 74-21) and those expected from a metallic system. More specifically, the similarities of the two systems regarding convection-induced dendrite fragmentation and its effects are of primary interest.

Approach

Three different alloys will be melted prior to flight and then frozen rapidly during a low-gravity descent by a gaseous quench on opposite mold sides, which is similar to the thermal configuration used with the metal model system flown on SPAR I (Experiment 74-21). The grain morphologies and macrosegregation will then be compared to appropriate ground-based specimens.

Expected Results

Comparative analyses of flight and ground-based tests may support the convection-induced dendrite fragmentation process observed on SPAR Experiment 74-21. Close scrutiny of the metal system/ metal model system results will substantiate the accepted technique of investigating metal solidification by direct observation of metal model systems.

Status

The special furnace for this experiment is near completion, and the experiment has been selected for SPAR VII.

Publication

Johnston, M. H. and Griner, C. S.: Compositional Variations in the Undercooled Pb-Sn Eutectic Solidified at Various Acceleration Levels. Scripta Metallurgica, Vol. 11, 1977, p. 253.

UNIDIRECTIONAL SOLIDIFICATION OF MONOTECTIC AND HYPERMONOTECTIC ALUMINUM-INDIUM ALLOYS

SPAR Experiment 76-51

Principal Investigator: C. Potard
French Atomic Energy Commission
Nuclear Research Center of Grenoble

Science Advisor: R. C. Ruff
ES74, MSFC

Objective

The objective of this experiment is to study the solid structure formed during zero-gravity solidification of monotectic and hypermonotectic Al-In alloys and to provide optimum thermal and composition parameter values for obtaining regular structures.

This SPAR experiment constitutes an essential preparation stage for Spacelab experiment ESA-MS 88, which has the objective of preparing Al-In samples with a controlled dispersoid structure of In globules in an Al-In matrix.

Rationale

Metallic binary systems having an immiscibility gap in the liquid state form a broad family (approximately 350 systems) which has not been exploited because of the great difficulty of preparation on Earth. Experiments in space are necessary to determine if fine, long-range dispersoid solid structures can be obtained in the absence of buoyancy forces.

Approach

Samples of monotectic (5 at% In) and hypermonotectic (10 at% In) composition will be solidified under various thermal conditions during zero gravity. The General Purpose Rocket Furnace — Gradient Version will be used to solidify the samples at both high and low thermal gradients. The samples will be contained in silicon carbide coated graphite crucibles. It has been shown that SiC will preferentially be wetted by the aluminum-rich phase, with the result that surface convection will be minimized. Also, the SiC will not act as a nucleation site or sink for the In-rich globules as they are formed.

Expected Results

The degree and uniformity of dispersion of the second phase will be measured. This will be compared to theoretical models of the solidification process. The models will then be updated with the experimental results and used to define the experimental parameters for the subsequent Spacelab 1 experiment.

Status

The experiment has been selected to fly on SPAR VI.

Publications

1. Potard, C.: A Review of the Mechanisms Involved in the Directional Solidification of Al-In Emulsions at Zero Gravity. Journal of the British Interplanetary Society, Vol. 31, 1978, pp. 275-280.

2. Potard, C.: Directional Solidification of Al-In Immiscible Alloys under Microgravity-Definition of the F-AEC/SPAR Experiment. ESRANGE Symposium (ESA-SP-135), Ajaccio, France, April 24-29, 1978, p. 339.

FOAM COPPER

SPAR Experiment 77-9

Principal Investigator: Robert B. Pond, Sr.
Marvalaud, Inc., and The Johns Hopkins University

Co-Investigators: John M. Winter, Jr., Da 'd A. Shifler, and : uce S. Tibbetts
Marvalaud, Inc.

Science Advisor: Don Reiss
ES74, MSFC

Objective

The objective of this experiment is to produce a copper foam with homogeneous porosity and a density less than a third of that of pure copper.

Rationale

This experiment could lead to a new class of high-strength, low-density structural materials. Possible commercial applications for light, strong materials of this type could be found in automobiles and aircraft. Replacement of solid metal structural members with metal foams could reduce vehicle weights by hundreds of pounds, resulting in substantial reductions in fuel consumption without sacrificing load handling capacity. Since metal foams are formed by creating bubbles in a melt, the experiment must be done in the low-gravity environment of space to avoid segregation due to buoyancy. In space, the bubbles should remain at their nucleation sites until the melt solidifies, producing a homogeneous foam.

Approach

A sample consisting of copper, copper oxide, and graphite will be sealed in a metal cartridge and placed in the General Purpose Rocket Furnace. When a microgravity condition is achieved, the sample wil ɔe melted, allowing the copper oxide and graphite to come into contact and react, producing carbon monoxide bubbles. The sample will then be cooled, producing a solid copper foam.

Expected Results

A copper foam with a density a third or less of the density of pure copper will be produced. This sample will be chara terized using conventional quantitative metallographic techniques. The data obtained from this experiment should make it possible to design a recipe for producing copper foams of any desired density and bubble volume. It may be possible to extend these results to other useful alloys.

Status

This experiment has been selected for flight on SPAR VI.

PART III

EXPERIMENTS REQUIRING FURTHER DEVELOPMENT BEFORE FLIGHT ASSIGNMENT

PRODUCTION OF BULK METALLIC GLASSES IN SPACE

SPAR Experiment 74-49

Principal Investigator: Arthur Lord
Drexel University

Science Advisor: J. McClure
EH22, MSFC

Objective

The objective of this experiment is to explore the feasibility of containerless processes to produce metallic glass by severe undercooling while eliminating container-induced nucleation sites.

Rationale

When a metal or alloy solidifies, it usually divides into many small crystals. The atoms in each of these crystals are arranged in a periodic fashion known as a crystal lattice. Certain metal alloys, however, can be cooled so fast that the atoms do not have time to arrange themselves in a regular fashion but are instead arranged in a more or less random fashion like the atoms in ordinary glass. Such disordered materials are termed amorphous and have very different properties from the same material in a crystalline state. Present techniques for fast cooling of metals on Earth require that the metal be in very thin ribbon form so that heat can be extracted quickly. This space experiment will be an attempt to produce metallic glasses in bulk form by using containerless techniques to deny nucleation sites during extreme undercooling.

Approach

This objective will be accomplished by electromagnetically levitating the liquid metal and gas cooling the levitated melt. Since the liquid metal will not be in contact with a crucible, there will be fewer places where solidification can start. It is therefore expected that the metal can be cooled below its usual melting point so that when freezing does finally take place, the liquid will be so viscous that the atoms in the liquid cannot rearrange themselves into a crystal. It is necessary to do this experiment in space because the high power needed to levitate this material on Earth would heat the metal so much that it could not be solidified. The low gravity of space requires only a small amount of power to levitate and position the molten metal.

Expected Results

The first attempts will be made with a Pd-Si compound which forms a glassy state at moderate cooling rates. In later experiments more difficult systems will be investigated.

Status

The experiment was flown on SPAR IV but failed to melt because of an incorrect timer setting. A quench gas system has been added to the electromagnetic levitator. Cooling rate calculations have been completed. Additional ground-based work is being conducted to define experiment protocol.

CONTACT AND COALESCENCE OF VISCOUS AND VISCOELASTIC BODIES

SPAR Experiment 74-53

Principal Investigator: Donald R. Uhlmann
Massachusetts Institute of Technology

Science Advisor: Barbara Facemire
ES74, MSFC

Objective

The proposed investigation is intended to clarify and quantify the details of the physical processes whereby approximately spherical viscous and viscoelastic bodies contact and coalesce. The dependence of the flow field and geometry evolution upon parameters of recognized importance (including surface tension, material rheology, particle geometry, applied stress, etc.) as well as upon parameters not previously recognized is to be determined.

Rationale

The elucidation of the coalescence behavior (including initial contact) of viscous and viscoelastic fluids is very important in a number of materials processing situations. These include the thermal processing of phase-separating glasses, the deformation processing of phase-separated glass melts, the sintering of ceramic materials, the agglomeration of polymeric particles during melt processing, the solid processing of certain polymers (especially PTFE), and the high-pressure cold sintering of glassy polymers. The coalescence of molten droplets constitutes the mechanism for the formation of breccias; the present investigation would improve the accuracy of estimates of the thermal history of lunar breccias. An improved understanding of coalescence is important to the improved understanding of the rheology of suspensions, metal slushes and polymer solutions, and of certain biomedical problems involving agglomeration in multiphase flows. Coalescence is also an interesting free-boundary problem in hydrodynamics.

The necessity for gravity-free experiments arises from the fact that the principal interest in coalescence phenomena centers on situations in which gravitational effects are negligible, as with very small droplets; but under these conditions, it is almost impossible to study the flow fields of interest.

Approach

An extensive ground-based experimental and theoretical program will be undertaken to provide a sound basis for the proposed two SPAR flights. The acoustic levitation device will be used on SPAR to position and maneuver drops of viscous fluids. These drops will probably contain tracer particles and will be made to coalesce in the field of view of cameras so that the flow fields can be observed. Initial contact, coalescence behavior, and flow fields will be analyzed. These data will be used in addition to data from the ground experiments to develop a more adequate understanding of the coalescence phenomenon.

Results

The experiment was flown on SPAR III. Difficulty with the deployment of droplets of the viscous oil prevented useful results from being obtained.

Status

The deployment apparatus has been redesigned, and preliminary tests have indicated that the new deployment technique is feasible. Additional tests on the KC-135 are required before the experiment is ready for a SPAR flight assignment.

SOLIDIFICATION BEHAVIOR OF Al-In ALLOYS UNDER ZERO-GRAVITY ENVIRONMENT

SPAR Experiment 74-62

Principal Investigators. H. Ahlborn
University of Hamburg

K. Lohberg
Technical University Berlin

Science Advisor: Mike Robinson
ES74, MSFC

Objective

The objective of this experiment is to solidify under a low-gravity environment an aluminum-indium alloy with a fine, uniformly dispersed second phase. The physical and electrical properties could then be studied in the laboratory. Composition of the samples will be selected so that one sample will provide information concerning "spinodal decomposition."

Rationale

Since the aluminum-indium system has an immiscibility gap in the liquid state, the two materials will separate into two interdispersed liquids upon cooling. Before solidification can occur in ground-based tests, the droplets of the higher specific gravity indium will sink and the two liquids thus completely separate. Agglomeration of the droplets will also be enhanced by thermal convection. Since the separation process is gravity-driven, it becomes necessary to process the aluminum-indium alloys in a low-gravity environment, such as provided in the SPAR flights, to produce an alloy with a fine, uniformly dispersed second phase.

Approach

Pure indium and pure aluminum starting materials will be enclosed in an alumina crucible cartridge. Two cartridges will be provided, one aluminum-rich and the other indium-rich. Prior to launch, the samples will be heated to 900°C and held at that temperature until the low-gravity portion of the flight is reached. The cartridges will then be cooled and the alloys solidified. After recovery, the samples will be studied to determine their physical and electrical properties as well as their microstructure.

Results

The experiment was flown on SPAR II. The recovered sample showed massive segregation as a result of inadequate mixing or low-gravity forces.

Status

A reflight of this experiment has not been rescheduled for a specific SPAR flight.

CHARGED DROP OSCILLATIONS

SPAR Experiment 76-19

Principal Investigator: Clive P. R. Saunders
University of Manchester Institute
of Science and Technology
Manchester, England

Science Advisor: Warren Campbell
ES82, MSFC

Objective

One objective of this experiment is to determine the effect of electrical charges on the vibrational frequency of water drops. This is to check Rayleigh's theory for small drop oscillations. Large drop oscillations will also be studied.

Another objective is to determine the manner in which drops behave when they are charged sufficiently high for the surface energy to tend toward zero (surface charge counteracts surface tension). How does fission occur?

Rationale

Charged-drop oscillations are important in rain cloud dynamics. Radar echoes from clouds have been shown to contain a time-varying component due to the vibration of raindrops, which are likely to contain varying amounts of charge. Drop oscillation frequency is dependent upon surface charge and drop radius. The intensity of the returned radar signal is a function of both drop size and concentration, and thus an independent assessment of drop size would permit cloud particle concentrations to be determined by radar. A radar has been built to examine this possibility. Oscillation frequency change caused by drop charge would give a false indication of size.

In space the drop dynamics module provides a means of charging and acoustically levitating and exciting oscillations in a drop. This work cannot be done adequately on Earth. In laboratories, drop oscillation experiments involve suspending drops from strings or in a vertical air stream. Both of these techniques distort the drop shape and possibly change oscillation frequency.

Approach

Three drops 0.5 cm in diameter will be acoustically levitated, charged, and their oscillations excited. The three drops will be charged to 2.4 kV, 4.8 kV, and 7.1 kV (8 kV will disrupt the drop). Drop vibrations decay due to viscosity; therefore, oscillations can be observed as they die out and a changing oscillation frequency as a function of amplitude can be observed.

At the high charging potential, large amplitude oscillations can be expected to cause drop fission.

Drop oscillations are expected to follow Rayleigh's theory; i.e., as the large-scale oscillation amplitude decays, the oscillation frequency will approach the theoretical result. For large-scale oscillations, the frequency should be a function of oscillation amplitude. Theory for this nonlinear oscillation is not available, and the form of the variation is not known.

Another question is whether fission will occur to two drops or to more than two drops. This question has strong relevance to rain cloud dynamics.

For large oscillations, higher modes may be excited.

Status

The apparatus for the experiment is under development. Experiments to test the deployment of the drops and the insertion of the charging probe have been conducted on the KC135 flying parabolic trajectories. A flight assignment for this experiment has not been made.

DENDRITIC SOLIDIFICATION AT SMALL SUPERCOOLING

SPAR Experiment 76-39

Principal Investigator: Martin E. Glicksman
Rensselaer Polytechnic Institute

Science Advisor: L. L. Lacy
ES74, MSFC

Objective

The objective of this experiment is to measure the dendritic growth velocity of a well-characterized, high-purity material in a low-gravity environment under conditions of small supercooling.

Rationale

Dendritic solidification involves both a diffusive and convective heat transport process. Recent studies show that the diffusive component varies almost cubically with the supercooling; whereas the convective component varies linearly. Consequently, under terrestrial conditions, dendritic growth tends to be dominated by diffusion at medium-to-large supercooling and by convection at low supercooling (i.e., $\Delta T \lesssim 1$ K). This circumstance is unfortunate for precise experimental studies on the kinetics and morphology of growth, since present theories of dendritic growth become inapplicable at small supercooling. In a low-gravity environment, convection would be greatly reduced, thereby extending to lower supercooling the useful range of experimentation.

Approach

This experiment will use a specially designed apparatus that will accurately control and measure the undercooling of a high-purity liquid (succinonitrile) to within ±10 mK at an undercooling in the range of 0.1 to 1 K. Crystal growth will be initiated after achieving quiescent conditions. The dendritic crystal growth will be photographed in two planes so that accurate quantitative measurements can be made to determine the morphology and growth velocities of the system.

Expected Results

Comparison of the low-gravity and one-gravity growth behavior would permit direct assessment of the relative roles played by convective and diffusive transport during solidification and add significantly to our fundamental understanding of solidification and crystal growth processes both on Earth and in space.

Publications

1. Glicksman, M. E.: Convective and Diffusive Effects During Dendritic Solidification. AIAA 15th Aerospace Sciences Meeting, Huntsville, Alabama, January 1978.

2. Glicksman, M. E.: Influence of Spacial Orientation on the Kinetics of Convecto-Diffusive Dendritic Crystal Growth. COSPAR Paper VIII 2.1, Innsbruck, Austria, June 1978.

3. Glicksman. M. E. and Huang, S. C.: Influence of Spacial Orientation on the Kinetics of Convecto-Diffusive Dendritic Crystal Growth. American Conference on Crystal Growth IV, July 1978.

4. Glicksman, M. E.: Convective Heat Transfer During Dendritic Solidification. 13th Meeting Society of Engineering Science, Gainesville, Florida, December 1978.

5. Glicksman, M. E. and Huang, S. C.: Convective and Diffusion Effects During Dendritic Solidification. AIAA Paper 79-0029, January 1979.

LIQUID METAL DIFFUSION IN SOLUBILITY GAP MATERIALS

SPAR Experiment 77-7

Principal Investigator: Robert B. Pond, Sr.
Marvalaud, Inc.

Science Advisor: Don Reiss
ES74, MSFC

Objective

The objective of this experiment is to measure the diffusion rate of two liquid metals in one another for systems that exhibit a solubility gap.

Rationale

There are difficulties in making diffusion measurements in liquid metal systems, particularly those exhibiting solubility gaps. Particles of the lower density phase that nucleate as the temperature is lowered precipitate out, yielding erroneous diffusion rate data. Rapid quenching minimizes this motion but takes the system out of equilibrium and may introduce uncontrolled convection that could alter the diffusion profile. This may or may not introduce errors into the data. The elimination of gravity-driven convection in a flight experiment will preserve the positions of the precipitated particles, allowing more reliable measurements of diffusion rate to be made on these systems. This will provide a check on the validity of the rapid-quench method.

Approach

Ground-based experiments are being performed on Pb-Zn diffusion couples to establish the effects of convective mixing and the degree to which it can be controlled. A number of different combinations of temperature, time at temperature, couple diameter, and orientation relative to gravity will be used. The samples will be subjected to metallographic examination after quench. These experiments will determine whether it is advantageous to perform this type of measurement in a low-gravity environment.

Results

A new technique for forming diffusion couples has been developed which eliminates the difficulties with oxide formation at the interface. This consists of inserting wires made of each of the two components of the system into holes drilled through the sides of a graphite cylinder that has been split along a diameter. The two halves are displaced along the axis so that holes in one half line up with holes in the other, and the wires are inserted so that each wire extends into both halves. After the wires are melted, the two halves are slid back into their original positions, shearing the molten metal columns and bringing them in contact to form diffusion couples. A number of ground-based experiments have been run using this technique with Pb–Zn diffusion couples. The specimens are being analyzed, and a final report should be available by the end of 1979.

EXPERIMENTAL STUDY OF BUBBLE MOTION IN A THERMAL GRADIENT UNDER ZERO-GRAVITY CONDITIONS

SPAR Experiment 77-13

Principal Investigator: W. R. Wilcox
Clarkson College of Technology

Co-Investigator: H. D. Smith
Westinghouse R&D Center

Science Advisor: Barbara Facemire
ES74, MSFC

Objective

The objective of this experiment is to obtain data on bubble migration in a thermal gradient in the low-gravity environment in order to refine existing theory for thermal fining of glasses in space, and to analyze and compare observed motion with theory.

Rationale

In the formation of glasses, bubbles become entrapped in the melting mixture. Removal of these bubbles, "fining," is necessary to render the glass transparent and to provide usable strength levels. Three basic methods are involved in fining: buoyant fining (the bubbles rise in the gravitational field), chemical fining (adding fining agents that reduce the amount of gas and/or increase the rate of diffusion of gas out of the glass), and thermal fining (migration of bubbles in an imposed thermal gradient to the glass surface). Proposals for the formation of improved or unique glasses in space will require a thorough understanding of fining in the absence of gravity. Buoyant fining will not be applicable in space. If artificial gravitational fields were used, they would nullify the potential benefits of zero gravity to some of the experiments, such as studies of the homogeneous nucleation of crystallizing glasses. Chemical fining may not be applicable in cases where fining agents would add unwanted impurities. Migration of bubbles under a temperature gradient could indeed serve as a fining mechanism in zero gravity for the production of bubble-free melts.

Therefore, there is a need to have a quantitative understanding of the movement of bubbles in a thermal gradient. Such data would benefit future space experiments as well as lend control and understanding to the fining process on Earth. The necessary studies of thermal fining cannot be performed on Earth because (1) the bubbles are affected by buoyant forces, with larger bubbles moving faster than smaller ones, and (2) buoyancy-driven natural convection causes global movement of the glass melt and irregular thermal losses from the apparatus. Although the second effects can be circumvented on Earth to a great degree by various techniques, the first effect requires low-gravity conditions for unequivocal study.

Approach

A hot stage with attached low power microscopy and photography will be used. The hot stage design allows a thermal gradient to be imposed across a glass sample containing preformed bubbles. The migration of these bubbles is then recorded photographically (at approximately 1 frame per second). Temperature data will be telemetered. Thermal, gravitational, and photographic data will be analyzed to develop theoretical predictive techniques. Three flights are proposed in order to vary surface tension, surface tension temperature coefficients, temperature, thermal gradient, viscosity, and volatility to develop an adequate theoretical model.

Expected Results

New and reliable theoretical models should be obtained for bubble migration due to thermal gradients in a molten glass. These formulations should prove to be of great and widespread interest to the community of glass technologists. Additionally, this theory should serve as the foundation for the adaptation of this mechanism to the fining of glasses, ceramics, and metals manufactured in space.

Status

The experiment hardware is under development. No flight assignment has been made at this time.

Publications

1. Mattox D. M.; Smith, H. D.; Wilcox, W.; and Subramanian, R. S.: The Migration of Bubbles in Molten Glass Due to Thermal Gradients. Presented at the meeting of the American Ceramics Society, May 1978.

2. Wilcox, W.; Subramanian, R. S.; Papazian, J. M.; Smith, H. D.; and Mattox, D. M.: Screening of Liquids for Thermocapillary Bubble Movement. Submitted to the AIAA Journal.

DYNAMICS OF LIQUID BUBBLES

SPAR Experiment 77-18

Principal Investigator: T. G. Wang
Jet Propulsion Laboratory

Co-Investigators: D. D. Elleman
Jet Propulsion Laboratory

R. Nolen
KMS Fusion

Science Advisor: W. Oran
ES72, MSFC

Objective

This is an experimental research program that will contribute to the understanding of containerless processing of fusion targets — microballoons — in space. Specifically, it will study these aspects of containerless processing of fusion targets in space:

1. Determine the sphericity of a positioned liquid bubble.

2. Determine the efficiency of bubble centering by rotation and induced oscillation.

3. Study the natural resonance frequencies and damping mechanism of bubble oscillation.

4. Study the adiabatic expansion of liquid bubbles to better understand any physical processes limiting the shell thickness and bubble size.

Rationale

Thermonuclear fusion is an extremely important scientific endeavor. One area of fusion research known as inertial confinement is attained by irradiating a target with extremely high intensity beams. The targets are hollow spherical shells, most often glass, filled with deuterium and tritium.

The requirements on the uniformity of the shell thickness and sphericity of the target are very severe, and little is known about the formation of acceptable targets.

A simple but approximate model for bubble-shell centering may be the liquid bubble. Study of the centering of the inner gas bubble with the liquid-film container at constant temperature could be used to correlate viscosity effects, surface tension, gravity, centrifugal forces, and acoustic forces necessary to maintain the liquid bubble in position. A difficult task in studying glass shell formation directly is the high temperature needed to maintain glass viscosity in a workable range. Therefore, the liquid bubble appears a simple approximation for studying bubble-shell centering.

This experiment will study the stability and ability to manipulate liquid bubbles at room temperature to better understand the physics of fusion targets and assess the capability of fabricating fusion targets in a zero-gravity environment.

Approach

The experiment will use a three-axis acoustic positioning system developed by the Jet Propulsion Laboratory. A liquid drop will be deployed, and an air bubble will be injected into the center. The liquid drop with air bubble will be spun up by varying the phase between two of the acoustic drivers. The rotation rate will be allowed to decay freely. The acoustic power will be frequency modulated to drive the drop in its first and third normal modes of oscillation. The drop oscillation will be allowed to decay freely. Data will be obtained with a cine camera at 64 frames per second.

Expected Results

This study will provide a better physical understanding of containerless processing of fusion targets and will contribute to the sciences of drop dynamics and glass technology. Specifically, the experiment will:

1. Determine the sphericity of a positioned liquid bubble.

2. Obtain data on the damping constant of liquid bubbles.

3. Obtain data on the centering force generated by rotation and induced oscillation.

4. Investigate phenomena associated with adiabatic expansion of the bubble/drop.

Status

The design of this experiment has been established. The SPAR apparatus has not yet been assembled.

CONTINUOUS FLOW ELECTROPHORETIC SEPARATOR DEVELOPMENT

SPAR Experiment 77-E

Principal Investigator and
Science Advisor: R. S. Synder
ES73, MSFC

Co-Investigators: G. V. F. Seaman
University of Oregon

D. A. Saville
Princeton University

A. J. Johnson
New York University Medical Center

Objective

The experiment objectives are to predict the performance characteristics of the continuous flow electrophoresis units employed at unit gravity and in a microgravity environment; to develop a general and realistic mathematical model of continuous flow electrophoresis, taking into account the present state of knowledge; to project the magnitude of the advantages of microgravity processing; and to separate biological cells under conditions that optimize both the resolution and condition of the separation species.

Rationale

The available apparatus for continuous flow experimentation and prepara tion of purified biological materials have been designed by essentially empirical methods. Continuous flow electrophoresis involves a large number of interacting phenomena. Our understanding of the basic processes as they operate in such devices is incomplete and fragmented, since typically the operation of the instrument is described solely from the viewpoint of one or another discipline. Thus, the theoretical models developed thus far for these apparatus are of limited value for establishing the limitations of the devices operated under different conditions or projecting realistic optimal system designs.

Approach

To provide the basic framework of theory, design concepts, etc., which will establish the optimal apparatus designs and their limitations on the ground and in space, a multidisciplinary effort including a team of scientists representing fluid dynamics, separation processes, and biology has been assembled. Integration of the team's effort in a stepwise approach will provide an understanding of the problems of continuous flow electrophoresis on the ground and in space. Operation of a transparent electrophoresis chamber under carefully controlled experimental conditions will be compared to flight experiments using major parts of an electrophoretic separator manufactured for SPAR.

Expected Results

Laboratory results and theoretical models with space experiments will provide a complete understanding of continuous flow electrophoresis and the conditions required to yield high-resolution, high-throughput separations.

Status

Laboratory tests and model development have shown sensitivity of the technique to thermal gradients.

Publications

1. Saville, D. A.: Fluid Mechanics of Continuous Flow Electrophoresis. Presented at 21st COSPAR Meeting, Innsbruck, Austria, 1978.

2. Rhodes, P. H.: High Resolution, Continuous Flow Electrophoresis in Microgravity. NASA TM-78158, 1978.

APPROVAL

DESCRIPTIONS OF SPACE PROCESSING APPLICATIONS ROCKET (SPAR) EXPERIMENTS

Edited by R. J. Naumann

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

CHARLES A. LUNDQUIST
Director, Space Sciences Laboratory

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