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CONTAINERLESS ELECTROMAGNETIC LEVITATION MELTING OF Cu-Fe AND Ag-Ni ALLOYS

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Space Science Laboratory

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16. ABSTRACT

This report summarizes one aspect of the work carried out in the Space Science Laboratory of Marshall Space Flight Center under a Technical Exchange Agreement with Eaton Corp. The general aim of this aspect of the program was to investigate the feasibility of producing silver or copper alloys containing finely dispersed nickel or iron particles, respectively, by utilizing containerless electromagnetic levitation casting techniques. A levitation coil was designed to successfully levitate and melt a variety of alloys including Nb-Ge, Cu-Fe, Fe-C, and Ag-Ni. The highest melt temperature acheived by the coil was about 2400°C during melting of Nb-Ge alloys. Samples of 70 Cu-30 Fe and 80 Ag-20 Ni (atomic %), prepared by mechanical pressing of the constituent powders, were levitated and heated either to the solid plus liquid range of the alloys or to the fully liquid region. The samples were then solidified by passing helium gas into the bell jar or they were dropped into a quenching oil. The structure of the samples which were heated to the solid plus liquid range consists of uniform distribution of Fe or Ni particles in their respective matrices. They also contained a considerable amount of entrapped gas bubbles. Upon heating for longer periods or to higher temperatures, the bubbles coalesced and burst, causing the samples to become fragmented and usually fall out of the coil. The structure of the Cu-Fe samples that were fully liquid and solidified while levitated consisted of the fine iron dendrites distributed uniformly in the copper matrix. For Ag-Ni samples, due to the existence of immiscibility gap in the fully liquid state, the nickel phase had separated into large islands within the silver matrix.

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INTRODUCTION

Copper and silver are widely used for electrical contact applications. However, their performance could be greatly improved if the metals were strengthened without sacrificing their electrical conductivity. A method to achieve this is by dispersion hardening of the metals by second phase particles which do not appreciably dissolve in the matrix. Dispersion of iron particles in copper and nickel particles in silver are good candidates for this purpose. However, due to the specific nature of Cu-Fe and Ag-Ni phase diagrams (Fig. 1) [Lyman, 1973], solidification of the alloys by conventional techniques results in formation of highly segregated and/or interconnected dendritic structure.

This work was performed under a technical exchange agreement (TEA) between Eaton Corporation and NASA. During the TEA samples of Ag-Ni and Cu-Fe were processed by a number of low-gravity and/or containerless processing techniques. A couple of samples of Ag-Ni were processed during low-g on a KC-135 aircraft. A few samples were prepared by ejecting them out of a crucible with an orifice and solidifying in free fall in a bell jar. The rest of the samples processed under the TEA were electromagnetic levitation induction melted in the Space Science Laboratory at MSFC. This report summarizes results from the latter experiments.

The major aim of this program was to utilize electromagnetic levitation technique to melt and solidify Cu-Fe and Ag-Ni samples, and to study the effect of electromagnetic stirring on the morphology of the second phase. These ground based experiments were intended to furnish information for low-g processing of the alloys.

EXPERIMENTAL PROCEDURE AND APPARATUS

The starting materials were supplied by the Cutler Hammer Company of Eaton Industries in the form of as-mechanically pressed cylinders of Ag-Ni (80-20 wt%) and Cu-Fe (70-30 wt%) powders. The samples, with a diameter of about 9 mm and height of 4 to 10 mm, were reportedly pressed for 30 and 60 Ksi. The average size of the particles were reported to be about 1 μm for Ag and a few microns for the other constituents.

A few Cu-Fe samples were also prepared by levitating proportionally weighed pieces of pure copper and iron, and allowing them to melt and mix with each other at the levitated state. These samples were used for comparison purposes with the samples prepared from the powders.

The levitation chamber, as shown schematically in Figure 2, consisted of a stainless steel chamber with a removable plexiglass top. The chamber had a view port on the side for measuring the temperature by an optical pyrometer. The levitation coil was located at the center of the chamber. A movable arm was attached to

the side of the tank which was used to hold a ceramic pedestal inside the coil. A sample was placed on top of the pedestal prior to levitation. After levitation, the mechanical arm was moved away, allowing the pedestal to fall out of the coil. A 10 kW, 300 kHz generator was used to power the coil. There were also arrangements for introducing Ar into the chamber or blowing He gas through the coil.

The levitation coil, made of fiberglass covered copper tubing with 0.095 in. O.D. and 0.039 in. I.D., is shown in Figure 3. It consisted of seven turns at the bottom and two reversed turns at the top. The lower part of the coil had a conical shape, with a vertical angle of about 15 deg.

The conical shape of the lower part is necessary to increase the levitation power of the coil. It also stabilizes the shape of the molten metal, thus preventing it from dripping out of the coil. The coil has been used to levitate and melt a variety of metals including steel, Cu-Fe, Ag-Ni, and Nb-Ge. The melt temperature of the latter reached about 2400°C.

The mechanically pressed samples were cut into semi-round shaped pieces of about 30 to 100 mm^3. The samples were then placed on the pedestal and the chamber was pumped down to about 50 millitorr before being back-filled with argon to about 200 millitorr. The power to the coil was then turned on, causing the sample to levitate and subsequently melt. At a desired temperature, the sample was either quenched in place by passing helium gas, or allowed to fall into a quenching oil or splat cool against a metal substrate.

RESULTS

Cu-Fe Samples

To levitate a Cu-Fe sample, it was necessary to heat the sample on the pedestal at a low power until its temperature exceeded the magnetic transformation (about 768°C) of the alloy. Beyond this temperature the power input to the coil was increased to levitate the sample. Application of the full levitation power to the sample at lower temperatures caused the sample to jump and stick to the coil.

After levitation, the copper constituent melted first. This was generally accompanied by swelling of the sample due to the expansion of the entrapped gases in the metal. The entrapped gases eventually exploded, causing the sample to disintegrate and fall out the coil. Sometimes, a large fragment of the sample remained levitated and was then heated up until the iron particles melted. Beyond this temperature, the sample formed a stable spherical shape, the temperature of which finally reached to a level corresponding to the power input, the gas pressure, and the sample size.

Microstructure of a sample which was heated to the solid plus liquid range is shown in Figure 4, in which iron particles and isolated pores within the matrix can be seen. This sample was quenched by helium gas. However, its structure is similar to those quenched in oil or splat cooled. The bonding between the matrix and particles is shown at a larger magnification in Figure 5. Small gas and shrinkage porosities can also be seen close to the iron particles. Although an optical pyrometer

was used to monitor the temperature throughout the experiments, the actual temperatures are not reported here because of the uncertainty of the pyrometer reading which is greatly affected by the surface conditions and other factors.

Microstructure of a sample which was fully melted and solidified in the levitated state by helium is shown in Figure 6. The structure consists of primary iron dendrites in the copper matrix, with some shrinkage holes close to the center of the sample. The dendrites were uniformly distributed across the sample.

Microstructure of a sample prepared from the bulk constituents which was fully molten and quenched in place by He is shown in Figure 7. The structure of another sample which was similarly prepared from the bulk materials, but was dropped in oil, is shown in Figure 8. The bottom part of the photograph shows the interface between the stainless steel oil container and the sample. Large segregates and banding can be seen clearly in the figure.

It should be noted that the microstructure shown in Figure 6 is very similar to that shown in Figure 7. As expected it indicates that once fully molten, the starting materials had no appreciable affect on the general microstructure. The contrast between Figures 7 and 8 clearly indicates the affect of electromagnetic stirring on the solidification.

Ag-Ni Sample

The behavior of 80 Ag-20 Ni samples during levitation was generally similar to that of Cu-Fe, except that Ag-Ni alloys are non-magnetic and levitate even at low temperatures. The expansion of entrapped gases frequently caused disintegration of the samples when the silver was melted. The structure of samples quenched from the solid plus liquid state showed non-uniform distribution of nickel particles in the silver matrix together with a considerable amount of porosity, as shown in Figure 9.

The structure of a sample which was quenched from the fully liquid state with helium gas is shown in Figure 10. In the photograph, which was taken with polarized light, the round shaped regions are gas holes. The gray colored areas represent the nickel phase. The time lag between the sample becoming fully liquid and being quenched was about 20 seconds, which was long enough to cause the two liquid phases to agglomerate. Holding the samples at the fully liquid state was also difficult due to rapid vaporization of silver which could cause coil failure.

DISCUSSION

Prior discussions with Chen (1982) about previous low-g and containerless experiments indicated that the Ag-Ni samples showed gross agglomeration of Ni particles as well as NiO formation. In the current work the magnetic stirring from the EM induction furnace dispersed the Ni phase to a finer degree than with the other processing techniques, but the size of the distributions apparently remains too coarse to be beneficial.

Other discussions with Chen (1982) indicated that the Cu-Fe samples produced by EM levitation melting showed "extremely interesting microstructures." In spite of this earlier optimism, analysis of samples prepared in this study indicates that the microstructural features are too coarse. It was desired to have submicron refinement

of the particle distribution. In conclusion, although the microstructures are interesting, the results do not look promising enough for further investigation.

SUMMARY

An electromagnetic levitation system was set up to successfully levitate and melt a variety of alloys including Nb-Ge, Cu-Fe, Fe-C, and Ag-Ni. The highest melt temperature achieved by the coil was about 2400°C during melting of Nb-Ge alloys. Samples of 70 Cu-30 Fe and 80 Ag-20 Ni, prepared by mechanical pressing of the constituent powders, were levitated and heated either to the solid plus liquid range of the alloys or to the fully liquid region. The samples were then solidified by passing helium gas or were dropped in a quenching oil. The structure of the samples which were heated to the solid plus liquid range consisted of uniform distribution of Fe or Ni particles in their respective matrices. They also contained a considerable amount of entrapped gas bubbles. Upon heating for longer periods or to higher temperatures, the bubbles usually coalesced and burst, causing the samples to become fragmented and fall out of the coil. The structure of the Cu-Fe samples that were fully liquid and solidified while levitated consisted of fine iron dendrites distributed uniformly in the copper matrix. For Ag-Ni samples, due to the existence of immiscibility gap in the fully liquid state, the nickel phase had separated into large islands within the silver matrix.

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Chen, C. G. (1982), Personal Communication, Eaton Corp., Milwaukee, WS.

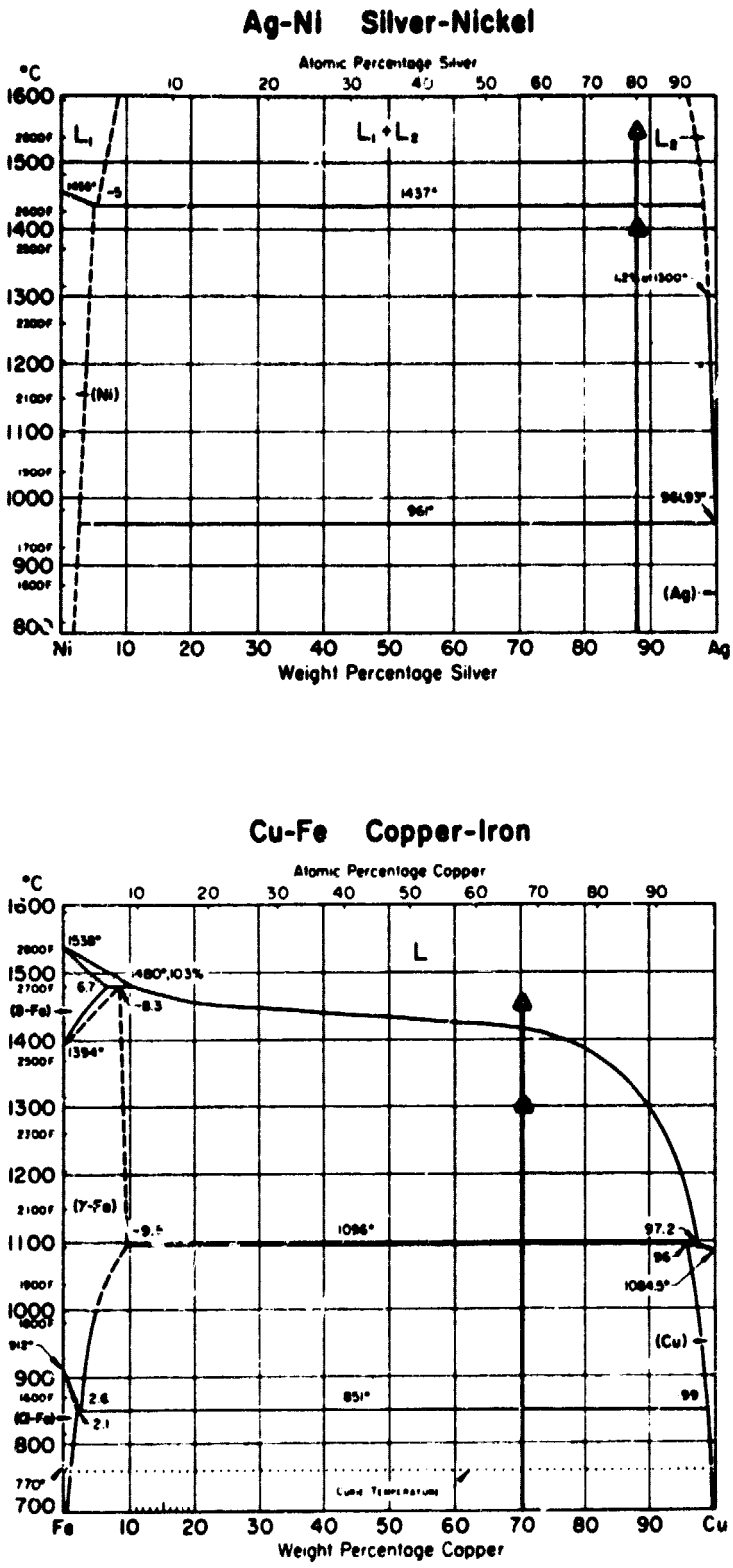

Figure 1. Phase diagrams for Cu-Fe and Ag-Ni.

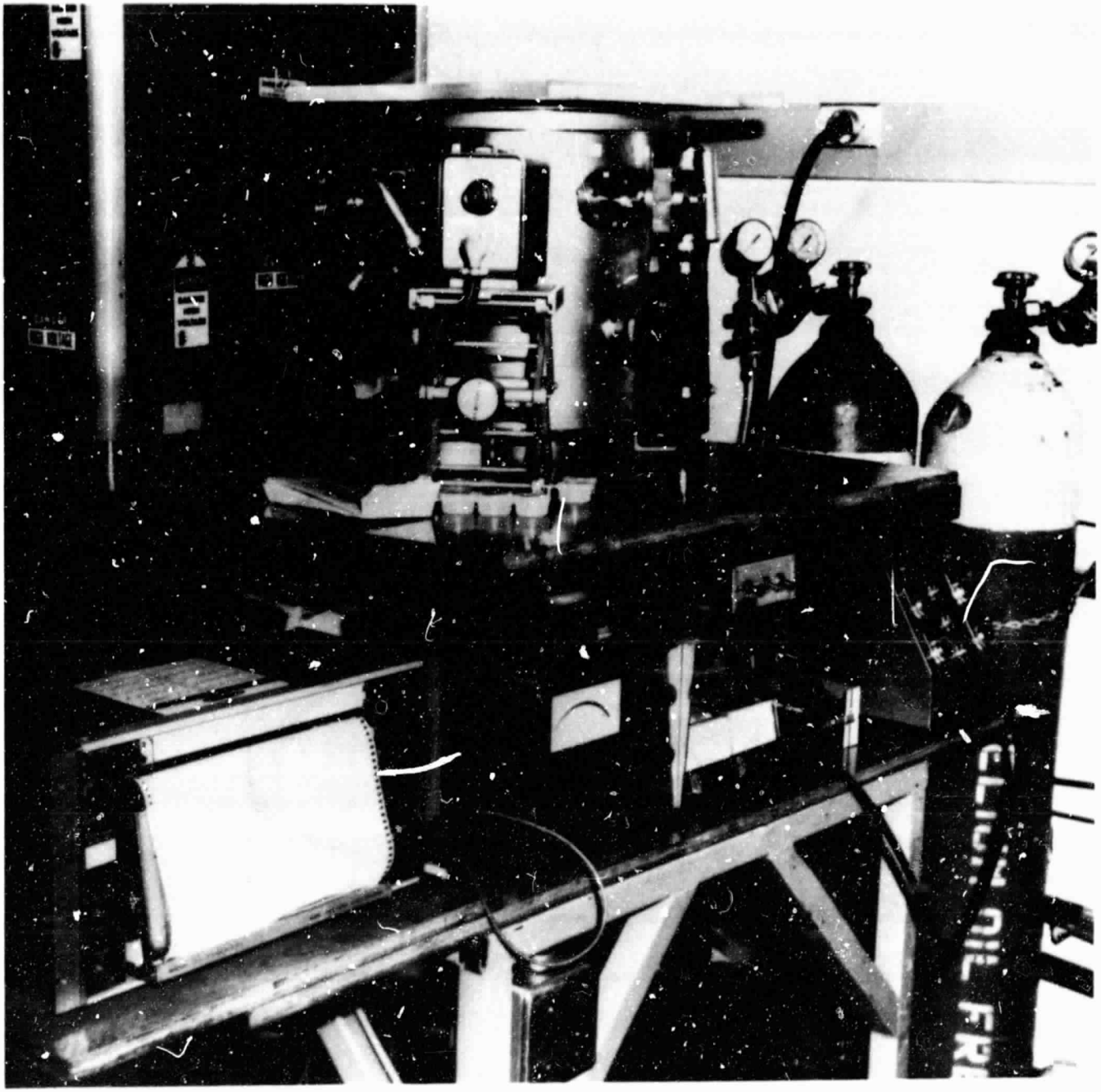

Figure 2. Photographic representation of the levitation chamber.

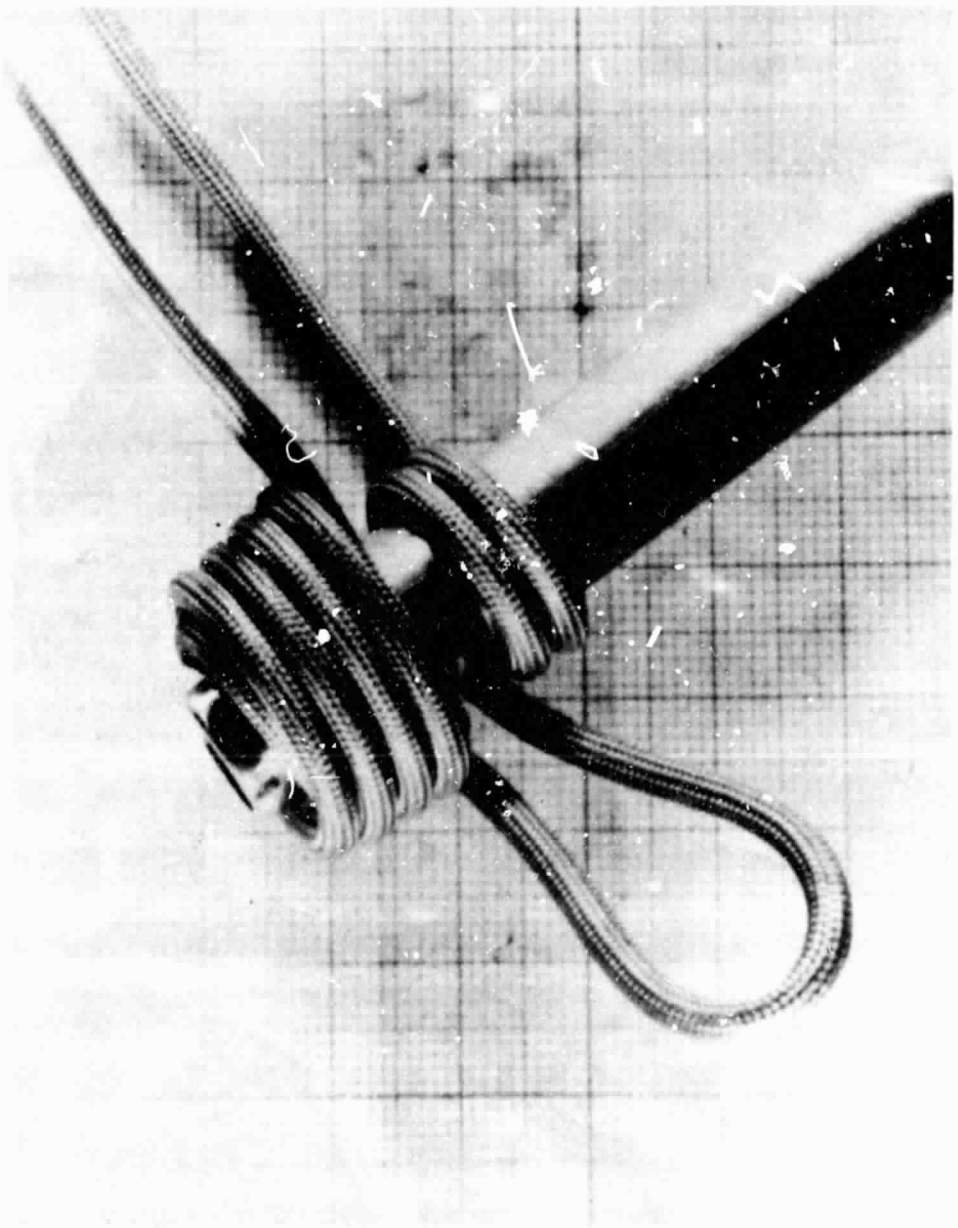

Figure 3. The levitation coil with seven turns at the bottom and two reversed turns at the top.

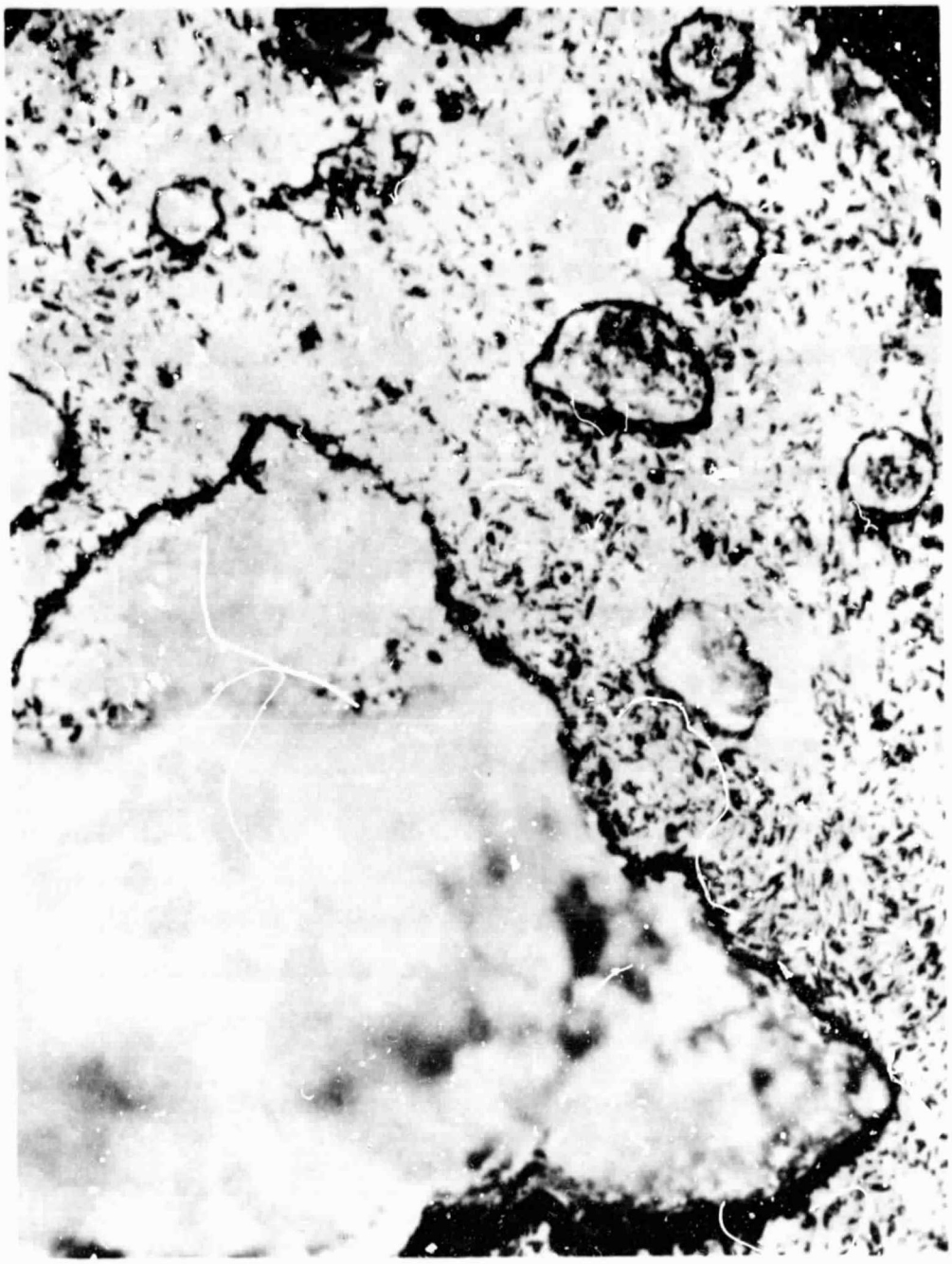

Figure 4. Microstructure of a Cu-Fe sample which was heated to the solid plus liquid range and quenched with helium (magnification 40X).

Figure 5. Iron particles in the copper matrix of a sample which was heated to the solid plus liquid range and quenched with helium (magnification 300X).

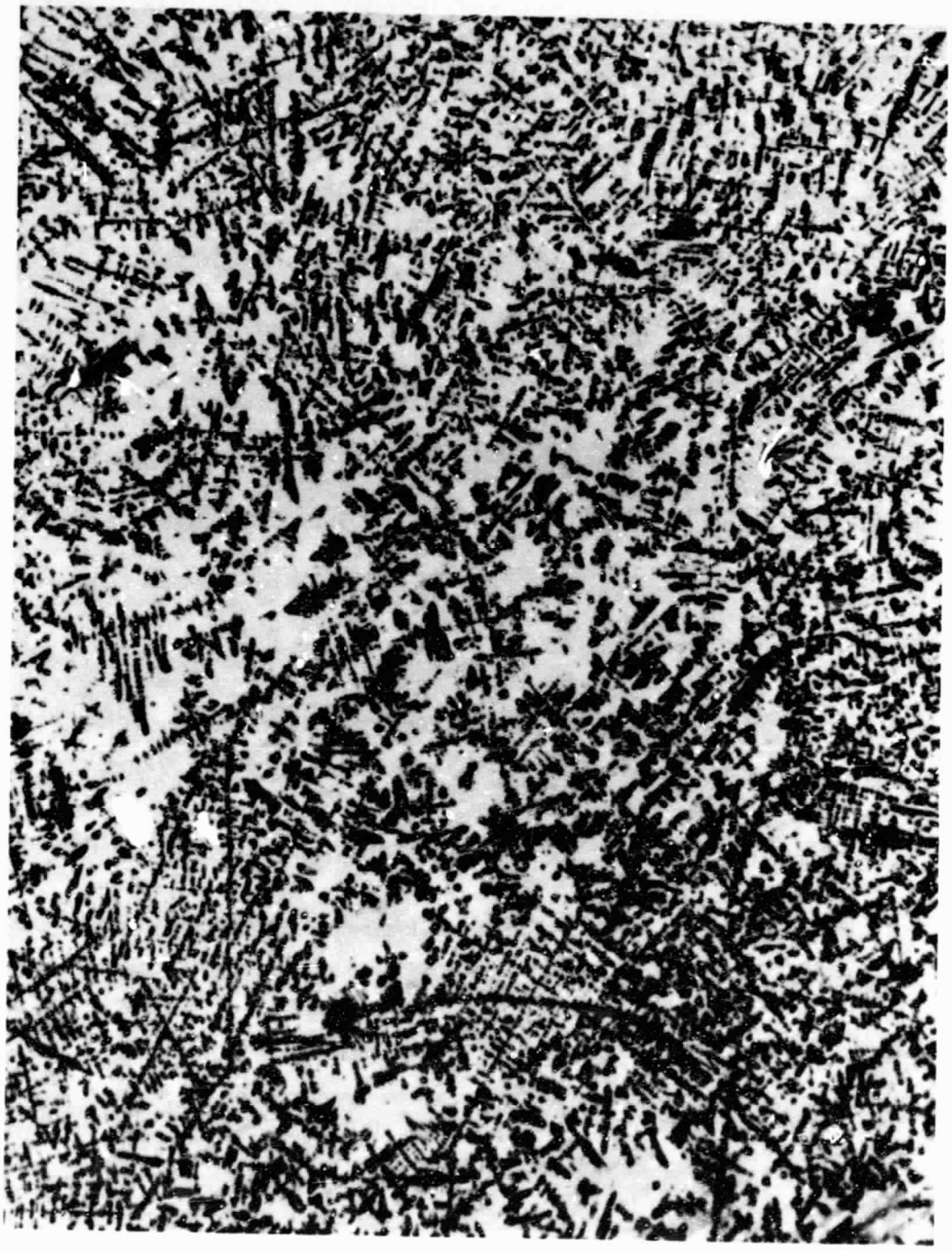

Figure 6. Microstructure of a Cu-Fe sample which was fully melted and quenched in the levitated state by helium gas (magnification 50X).

Figure 7. Microstructure of a Cu-Fe sample which was prepared from the bulk constituents, fully melted and quenched in the levitated state by helium gas (magnification 35X).

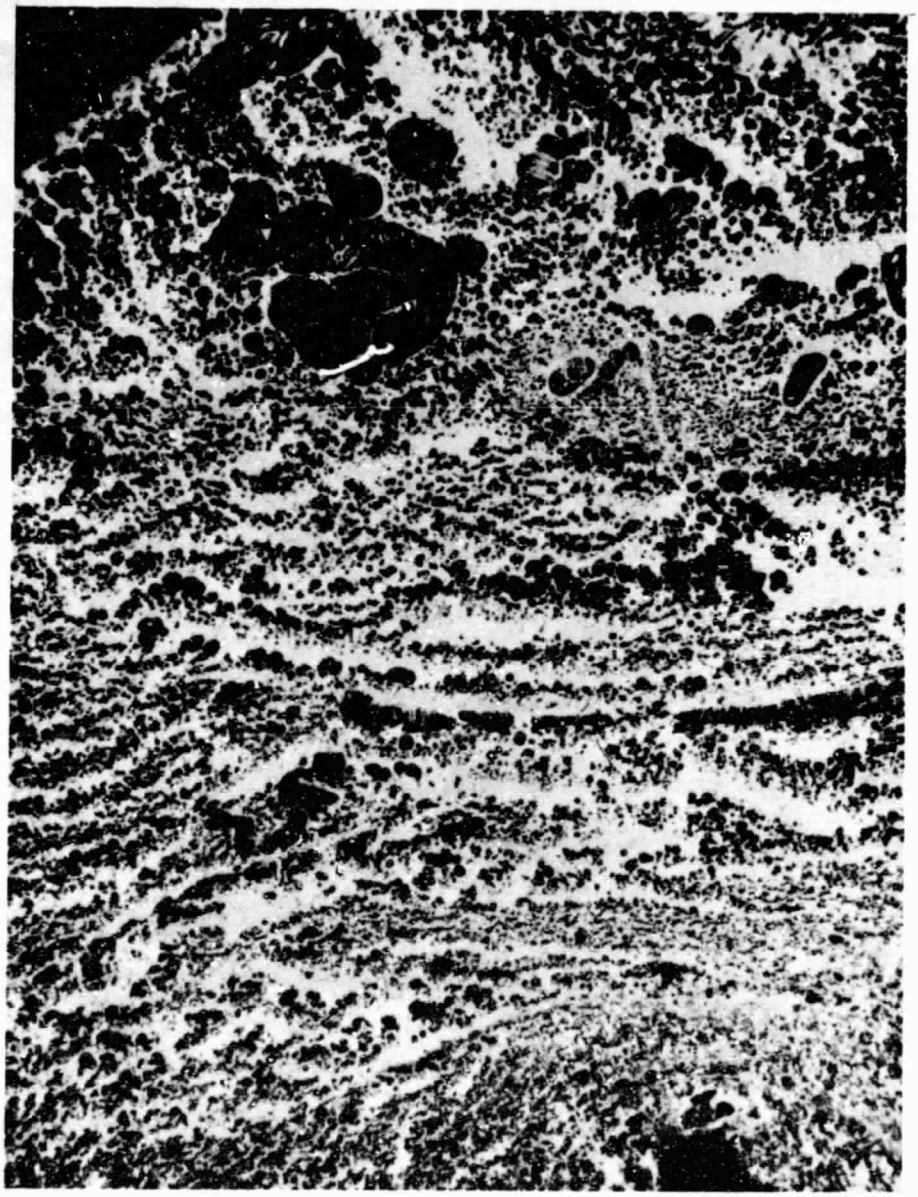

Figure 8. Microstructure of a Cu-Fe sample which was prepared similar to that in Figure 7, but was quenched in oil (magnification 40X).

Figure 9. Microstructure of an Ag-Ni sample heated to the solid plus liquid range and quenched with helium gas (magnification 50X).

Figure 10. Microstructure of an Ag-Ni which was fully liquid before being quenched with helium gas (magnification 35X).

APPROVAL

CONTAINERLESS ELECTROMAGNETIC LEVITATION MELTING OF Cu-Fe AND Ag-Ni ALLOYS

By G. J. Abbaschian and E. C. Ethridge

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.

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