N72. 25522

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-533

Investigation of Gold Embrittlement in Connector Solder Joints

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CALIFORNIA INSTITUTE OF TECHNOLOGY
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Prepared Under Contract No. NAS 7-100
National Aeronautics and Space Administration

PREFACE

The work described in this report was performed by the Engineering Mechanics Division of the Jet Propulsion Laboratory.

CONTENTS

I. Introduction 1

II. Test Procedures 2

A. Electron Microprobe Mapping 2

B. Mechanical Testing 3

III. Discussion 5

A. Electron Microprobe Mapping 5

B. Mechanical Testing 5

IV. Conclusion 7

References 8

TABLES

1. Electron microprobe gold mappings of joints 9

2. Tensile strength of solder joints 11

FIGURES

1. Sectional view of solder joint 12

2. Typical solder structure of tinned and wicked solder joints used for electron microprobe mappings 13

3. Typical solder structure of untinned and unwicked solder joints used for electron microprobe mappings 13

4. Harnesses mounted on vibration fixtures 14

5. Typical solder structure of solder in tinned and and wicked solder joints in mechanically tested harness 15

6. Typical solder structure of solder in untinned and unwicked solder joints in mechanically tested harness 15

ABSTRACT

An investigation was performed to determine to what extent, if any, typical flight connector solder joints may be embrittled by the presence of gold. In addition to mappings of gold content in connector solder joints by an electron microprobe analyzer, metallographic examinations and mechanical tests (thermal shock, vibration, impact and tensile strength) were also conducted. This report presents a description of the specimens and tests, a discussion of the data, and some conclusions.

I. INTRODUCTION

Since 1965, the soldering procedures at the Jet Propulsion Laboratory (JPL) have included provisions for wicking solder out of the solder cup area of electrical connector contacts after tinning and prior to assembly of wires and actual joint soldering. A reason that has been given for wicking is that it is a means to decrease the amount of gold in the solder joint, since embrittlement of joints is a possibility in any solder joint with a gold content greater than approximately 5% (Refs. 1-3). A cursory analysis of JPL flight connector solder joints indicates the possibility of 8.9% gold in a joint consisting of a 20-gauge wire in a 20-gauge solder cup.

In order to justify the elimination of further wicking of connector solder cups at JPL because of possible solder joint embrittlement by high gold content, it was decided that the following should be done:

(1) Determine the elemental constituents of selected areas of typical wicked and unwicked connector solder joints.

(2) Examine sectioned solder joints of both wicked and unwicked joints for the presence of $AuSn_4$, the white acicular crystals that are reported to be a cause of embrittled solder joints.

(3) Subject two harnesses (one with wicked connector solder joints and the other with unwicked joints) to thermal shock, vibration and mechanical shock.

The objective of the investigation reported here was to determine to what extent, if any, typical flight connector solder joints may be embrittled by the presence of gold.

II. TEST PROCEDURES

A. Electron Microprobe Mapping

After a detailed discussion of the problem with Dr. Arthur A. Chodos of the Geological and Planetary Science Department at the California Institute of Technology, it was decided that an analysis by an electron probe X-ray microanalyzer could provide data adequate to aid in determining the extent of gold embrittlement in soldered joints.

The electron microprobe at Caltech is computerized, and Dr. Chodos performed all of the electron microprobe work. S. P. Vango (Section 382, JPL) prepared the pure reference samples that were used by Dr. Chodos. The JPL Cable Fabrication Shop (Section 732) prepared and soldered joints, and Section 358 personnel prepared the mounts of the sectioned solder joints used for both the electron microprobe analysis and metallograph examinations.

There were a total of four mounts prepared, with each mount containing 10 longitudinally sectioned electrical connector contact solder joints. Two of these mounts contained sectioned solder joints prepared by a process consisting of soldering dip-tinned wires directly into untinned and unwicked solder cups. The other two mounts contained sectioned joints prepared by first tinning and wicking the solder cups and then soldering dip-tinned wires into the solder cups. Each sectioned solder joint of each mount was mapped by the electron microprobe in five selected areas for weight percentages of gold. The diameter of the microprobe beam was 1 micron. The areas mapped are shown in Fig. 1.

After the data was analyzed, it was decided that perhaps a beam diameter of 1 micron was not giving a true average of the constituents, since the beam diameter was small compared to the typical solder joint width. The percentages could range from high to low with only a slight change in beam location. A change in location corresponding to 2 or 3 diameters of the beam could change a gold data reading from 22% to perhaps 1%. In other words, it was believed that because the solder matrix was a solid solution containing solid precipitates of a size comparable to the beam, the reading of a given constituent would be high when the beam is covering a precipitate and then low in that same constituent when the beam is not covering the precipitate.

Under this condition, the 1-μm-diameter beam appears to be too small to obtain a true average in the joints tested.

Magnified pictures of the sectioned solder joints were scaled, and it was decided that a 20-μm beam should provide a more accurate average of constituent percentages for the selected number of areas to be mapped in joints of this size. During this testing, Dr. Chodos had also suggested improvement in specimen preparations that could influence the ease and accuracy of the determination.

Four completely new mounts were prepared and tested using a beam diameter of 20 μm. Tabulation of the gold data is presented in Table 1. The 20-μm-diameter beam was adequate for all of the areas of each of the specimens tested without being too large to overlap into other than the solder joint itself.

Since the reports by Foster (Refs. 1 and 3) indicate that white acicular crystals of $AuSn_4$ are the cause of embrittlement in solder joints due to gold in excess of 5%, any area of a mounted contact that corresponded to an electron microprobe gold data point greater than 4.5% was etched with $FeCl_3$ and examined for the presence of $AuSn_4$ at approximately 1000× magnification. Figures 2 and 3 are typical photomicrographs of areas of wicked and unwicked solder joints which were in the mounts used for the electron microprobe mappings.

B. Mechanical Testing

Two harnesses were fabricated by the Cable Shop (Section 732) on a vibration test fixture (see Fig. 4). One harness contained four 25-contact rectangular connectors per JPL Specification 20045/200, with solder joints that were produced by first tinning and wicking the solder cups and then soldering dip-tinned wires into the cups. Two of the four connectors of the one harness contained 20-gauge flight wires per JPL specification ZPH-2239-0940; the other two connectors of this harness contained 22-gauge flight wires. The other harness contained solder joints which were produced by soldering dip-tinned wires into the connector contact cups without first tinning and wicking the cups. Both harnesses contained the same numbers and types of connectors and wires.

Environmental Facility (Section 374) personnel subjected the harnesses and test fixture, at ambient pressure, to 10 cycles of thermal shock from -100 to 130°C. The fixture was then mounted on a vibration table, with the connector contacts horizontal to the table (one axis only), and subjected to sine vibration at a sweep rate of 1 octave/minute. The first run was from 50 Hz to 2 kHz at 15 peak g's. The second run was from 100 Hz to 2 kHz at 50 peak g's, and the third and final run was from 100 Hz to 2kHz at 100 peak g's. Each solder joint received a complete inspection at 10× magnification after each cycle of thermal shock, vibration and mechanical shock.

Next, the harnesses were removed from the vibration test fixture, and the solder joints in each connector were radiographed before removal of contact numbers 8, 10, 11, 12, 15, 16, 17 and 19. Contacts 11 and 16 from each connector were mounted and sectioned with all wicked joints in one mount and all unwicked solder joints in a separate mount. Figures 5 and 6 are photomicrographs of typical areas of the wicked and unwicked solder joints from the mechanically tested harnesses.

The solder joints in contacts 8, 10, 12, 15, 17 and 19 of each connector were tested in the Cable Shop by pulling the wires in straight (axial) tensile at a crosshead travel rate of 5.08 cm/min (2 in./min). Table 2 shows the results of these tensile strength tests of both 20- and 24-gauge wires in wicked and unwicked solder joints taken from the mechanically tested harnesses.

III. DISCUSSION

A. Electron Microprobe Mapping

According to the microprobe data in Table 1, there is a discernible difference between the amount of gold in the various areas mapped which is dependent upon the process used to prepare the solder joint. The tinned and wicked joints were very low in gold content, and metallographic examination at 1000× magnification did not disclose signs of $AuSn_4$ in the solder joint areas of any contact tested. Figure 2 shows the typical structure of all solder areas of each tinned and wicked solder joint. The highest weight percentage microprobe reading of gold in the tinned and wicked specimens was 4.6%, with the average being 0.6%.

The highest gold reading in the untinned and unwicked contacts was 10.3%, with the average being 2.8%. Figure 3 is typical of the solder joint areas of all untinned and unwicked contacts. Even though the solder joint areas of the untinned and unwicked contacts show the presence of the white acicular crystals of $AuSn_4$, the highest average gold content of an individual joint was 3.9%, with the lowest being 1.0% and an average of 2.8%. Three untinned and unwicked contacts each contained two mapped areas of gold exceeding 4.5%. Of these, the highest total joint gold content was 3.0%.

The solder joints mapped by the electron microprobe constitute the worst case, since the majority (99%) of the flight connector solder joints contain wires of smaller diameter in a 20-gauge contact solder cup and therefore have a larger amount of solder present in the joint as compared to the closer fitting 20-gauge wire/20-gauge cups tested for the same amount of gold.

B. Mechanical Testing

Each solder joint in the harness assembly was inspected for possible cracks after each cycle of thermal shock, vibration and mechanical shock. There were no visible cracks in any of the solder joints. The radiographs showed the solder joints to be typical of those produced on flight connectors.

Straight tensile pulls resulted in average values for all joints, with 20-gauge wires breaking at 14.97 to 16.78 kg (33 to 37 lb) and 24-gauge wires breaking at approximately 9.52 to 9.98 kg (21 to 22 lb). Table 2 shows the results of the solder joint tensile strength tests. Of the three joints that experienced wire pullout rather than wire breakage external of the joint, it was concluded that each was poorly prepared and incapable of offering data on gold embrittlement.

Metallographic examinations at a magnification of 1000× failed to show any signs of $AuSn_4$ in any tinned and wicked joints. However, the white acicular $AuSn_4$ crystals are present in all areas of each untinned and unwicked solder joint. Since electron microprobe data showed low average gold content and there were no mechanical failures, the conclusion can be made that even though $AuSn_4$ is present, it is not in concentrations sufficient to cause embrittlement.

IV. CONCLUSION

Since the maximum average gold content of all solder joints mapped by the electron microprobe was 2.8%, with one joint having a maximum average of only 3.9%, and there were no cracks in any joint after thermal shock (-100 to +130 °C), vibration (up to 100 g peak) and mechanical shock (200 peak g), it is concluded that untinned and unwicked JPL connector solder joints do not contain gold in quantities sufficient to cause embrittlement.

REFERENCES

1. Foster, F. G., "How to Avoid Embrittlement of Gold-Plated Solder Joints," Product Eng., August 19, 1963.

2. Harding, W. B., and Pressly, H. G., "Soldering to Gold Plating," 50th Annual Technical Proceedings of the American Electroplaters' Society, 1963.

3. Foster, F. G., "Embrittlement of Solder by Gold from Plated Surfaces," Papers on Soldering, STP 319, American Society for Testing and Materials, June 24, 1962.

Table 1. Electron microprobe gold mappings of joints

SPECIMEN LEGEND

PRESOLDERING CONDITION: TWS = TIN, WICK, SOLDER; S = NO TIN, NO WICK, SOLDER

METALLOGRAPH MOUNT

ELECTRICAL CONNECTOR CONTACT NO.

ELECTRON MICROPROBE MAPPING LOCATION (PER FIGURE 1.)

EXAMPLE: TWSB-2-4

NO TIN & NO WICK

SPECIMEN NUMBER	WEIGHT PERCENT(%) OF GOLD	AVG. GOLD PERCENT (%) IN JOINT	OVERALL AVG. GOLD (%)
SA-1-1	3.20		
2	5.86		
3	2.22		
4	1.71		
5	4.34		
5	0.28	2.93	
SA-2-1	4.21		
2	8.36		
3	3.84		
4	1.18		
5	1.00		
5	0.42	3.16	
SA-3-1	1.73		
2	5.19		
3	2.94		
4	1.27		
5	0.04	2.23	
SA-4-1	3.35		
2	3.76		
3	3.99		
4	3.74		
5	0.37	3.04	
SA-5-1	0.36		
2	0.71		
3	2.56		
4	0.40		
5	1.08	1.02	
SA-6-1	3.28		
2	10.34		
2	4.54		
3	----		
4	1.63		
5	0.00	3.95	
SA-7-1	3.01		
2	4.97		
3	6.04		
4	0.73		
5	0.00	2.95	
SA-8-1	4.73		
2	4.69		
3	----		
4	2.70		
5	0.04	3.04	
SA-9-1	2.27		
2	5.74		
3	3.91		
4	0.76		
5	0.26		

TIN & WICK

SPECIMEN NUMBER	WEIGHT PERCENT(%) OF GOLD	AVG. GOLD PERCENT (%) IN JOINT	OVERALL AVG. GOLD (%)
TWSA-1-1	1.08		
2	0.58		
3	0.27		
4	0.64		
5	0.11	0.53	
TWSA-2-1	1.99		
2	0.13		
3	0.82		
4	1.15		
5	0.15	0.84	
TWSA-3-1	0.56		
2	0.53		
3	----		
4	0.39		
5	0.50	0.44	
TWSA-4-1	0.61		
2	0.54		
3	1.89		
4	0.71		
5	0.32	0.86	
TWSA-5-1	0.26		
2	0.40		
3	0.48		
4	0.58		
5	0.34	0.41	
TWSA-6-1	0.22		
2	0.28		
3	0.22		
4	0.46		
5	0.06	0.24	
TWSA-7-1	1.18		
2	0.52		
3	----		
4	0.39		
5	0.47	0.64	
TWSA-8-1	0.53		
2	0.48		
3	0.23		
4	0.80		
5	0.00	0.26	
TWSA-9-1	0.73		
2	0.48		
3	0.20		
4	0.44		
5	0.00	0.37	
TWSA-10-1	0.59		
2	0.54		

FOLDOUT FRAME

1

SA-9-1	2.27		
2	5.74		
3	3.91		
4	0.76		
5	0.26	2.58	
SA-10-1	4.80		
2	4.06		
3	----		
4	1.38		
5	2.26	3.12	
SB-1-1	0.74		
2	0.55		
3	6,85		
4	0.07		
5	2.31	2.10	
SB-2-1	1.03		
2	3.91		
3	4.86		
4	2.83		
5	0.87	2.70	
SB-3-1	3.14		
2	4.72		
3	6.33		
4	0.60		
5	0.04	2.96	
SB-4-1	1.20		
2	8.62		
3	2.26		
4	1.72		
5	2.48	3.25	
SB-5-1	3.72		
2	2.95		
3	2.19		
4	3.76		
5	2.20	2.98	
SB-6-1	1.59		
2	4.78		
3	----		
4	3.48		
5	0.07	2.48	
SB-7-1	2.31		
2	1.06		
3	3.94		
4	1.93		
5	2.14	2.27	
SB-8-1	4.32		
2	2.48		
3	4.58		
4	1.28		
5	0.06	2.54	
SB-9-1	4.65		
2	4.19		
3	----		
4	6.37		
5	0.00	3.80	
SB-10-1	10.01		
2	3.05		
3	----		
4	2.26		
5	0.00	3.83	2.86

4	0.44		
5	0.00	0.37	
TWSA-10-1	0.59		
2	0.54		
3	----		
4	1.88		
4	2.10		
5	0.13	1.04	
TWSB-1-1	4.63		
2	0.57		
3	1.93		
3	1.80		
4	0.91		
5	0.06	1.38	
TWSB-2-1	1.21		
2	0.76		
3	----		
4	1.20		
5	0.10	0.81	
TWSB-3-1	1.00		
	0.37		
	0.65		
	1.27		
	0.51	0.76	
TWSB-4-1	2.14		
	1.29		
	0.93		
	(.29		
	1.45	1.22	
TWSB-5-1	0.11		
	0.47		
	0.27		
	0.45		
	0.37	0.33	
TWSB-6-1	0.58		
2	0.23		
3	0.24		
4	0.58		
5	0.30	0.38	
TWSB-7-1	3.39		
2	0.08		
3	----		
4	0.21		
5	0.16	0.96	
TWSB-8-1	0.61		
	0.52		
	0.20		
	1.18		
	0.08	0.51	
TWSB-9-1	0.50		
2	0.64		
3	0.71		
4	0,33		
5	0.06	0.44	
TWSB-10-1	0.54		
	0.22		

	0.62		
	0.22	0.40	0.64

FOLDOUT FRAME 2

Table 2. Tensile strength of solder joints (crosshead travel rate: 5.08 cm/min, 2 in./min)

Connector number	Contact number	Wire size, AWG number	Presoldering cup condition	Tensile strength, kg (lb)	Remarks
741-71	8	20	Tin and wick	15.19 (33.5)	Wire pulled out[a]
	10	20		16.55 (36.5)	Wire broke
	12	20		16.33 (36.0)	
	15	20		15.87 (35.0)	
	17	20		15.87 (35.0)	
	19	20		15.87 (35.0)	
741-134	8	24		9.98 (22.0)	
	10	24		9.98 (22.0)	
	12	24		9.98 (22.0)	
	15	24		9.98 (22.0)	
	17	24		9.98 (22.0)	
	19	24		9.98 (22.0)	
741-285	8	20		15.87 (35.0)	
	10	20		15.42 (34.0)	
	12	20		15.65 (34.5)	
	15	20		15.65 (34.5)	
	17	20		15.87 (35.0)	
	19	20		15.19 (33.5)	
741-51	8	24		9.98 (22.0)	
	10	24		9.98 (22.0)	
	12	24		9.30 (20.5)	
	15	24		9.98 (22.0)	
	17	24		9.98 (22.0)	
	19	24	Tin and wick	9.98 (22.0)	
741-311	8	20	No tin and no wick	16.55 (36.5)	
	10	20		16.33 (36.0)	
	12	20		16.33 (36.0)	
	15	20		16.79 (37.0)	
	17	20		16.55 (36.5)	
	19	20		16.55 (36.5)	
741-423	8	24		9.98 (22.0)	
	10	24		9.98 (22.0)	
	12	24		9.98 (22.0)	
	15	24		9.98 (22.0)	
	17	24		9.98 (22.0)	
	19	24		9.98 (22.0)	
741-37	8	20		16.55 (36.5)	
	10	20		16.55 (36.5)	
	12	20		16.55 (36.5)	
	15	20		16.33 (36.0)	
	17	20		16.55 (36.5)	Wire broke
	19	20		15.65 (34.5)	Wire pulled out[a]
741-35	8	24		10.20 (22.5)	Wire broke
	10	24		9.98 (22.0)	Wire broke
	12	24		9.52 (21.0)	Wire broke
	15	24		9.98 (22.0)	Wire pulled out[a]
	17	24		10.20 (22.5)	Wire broke
	19	24	No tin and no wick	10.20 (22.5)	Wire broke

[a]After a thorough inspection of both the wire and the solder cup, it has been concluded that the joint was poorly prepared and meaningful results concerning embrittlement cannot be inferred from the particular joint.

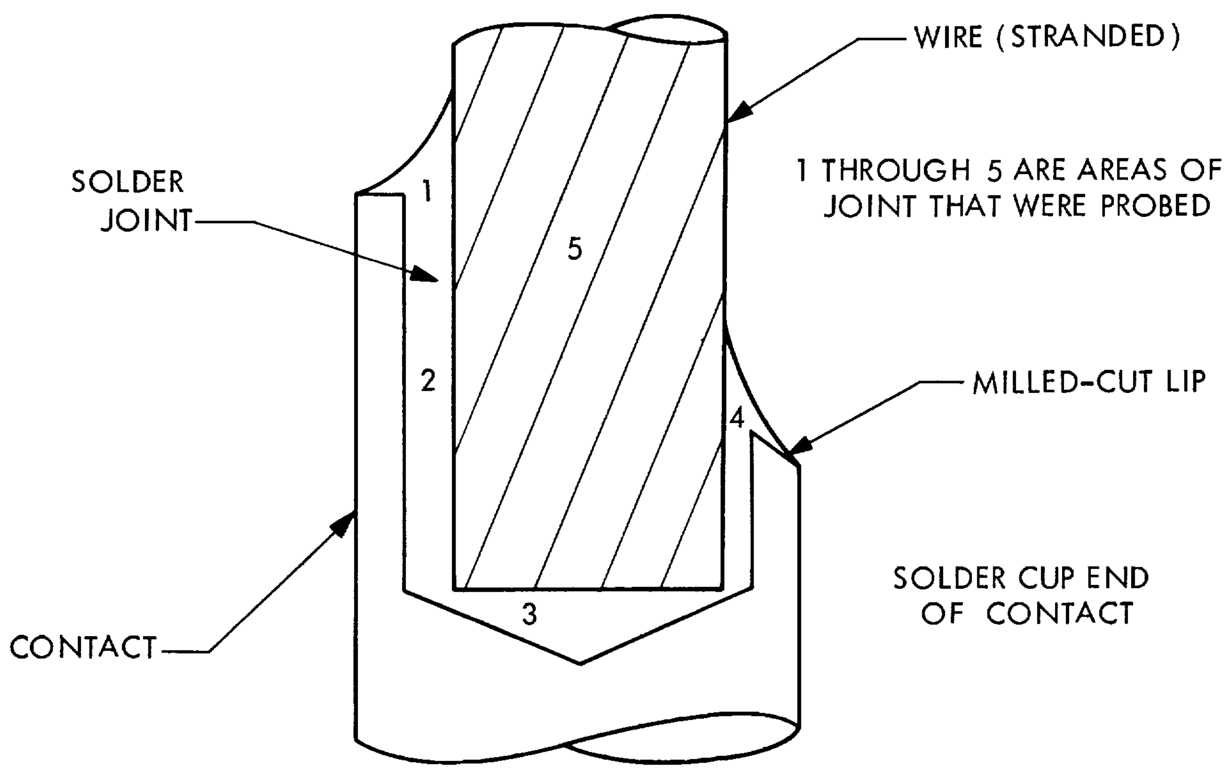

Fig. 1. Sectioned view of soldered joint

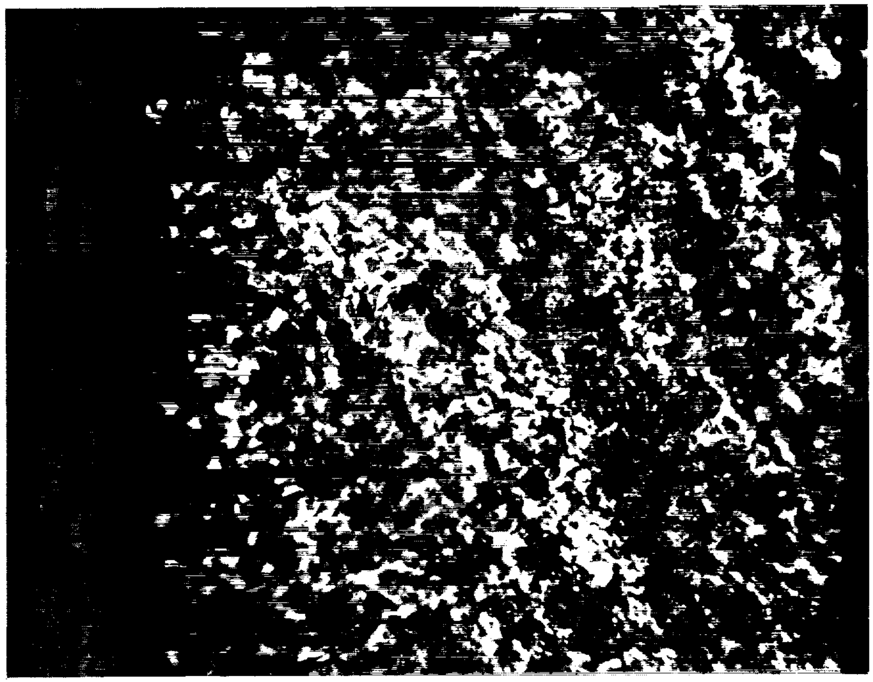

Fig. 2. Typical solder structure of tinned and wicked solder joints used for electron microprobe mappings (magnification 1000×)

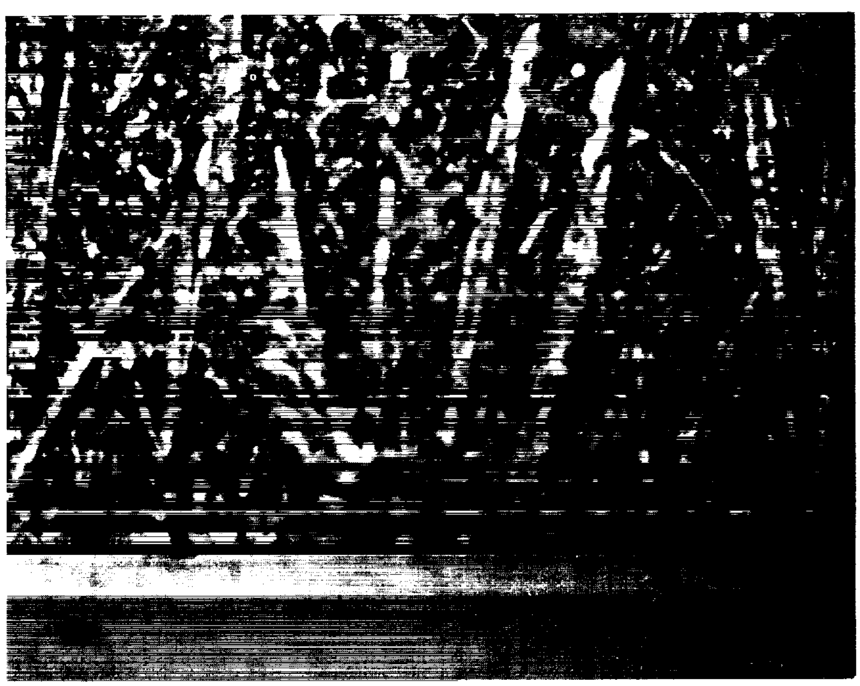

Fig. 3. Typical solder structure of untinned and unwicked solder joints used for electron microprobe mappings (magnification 1000×)

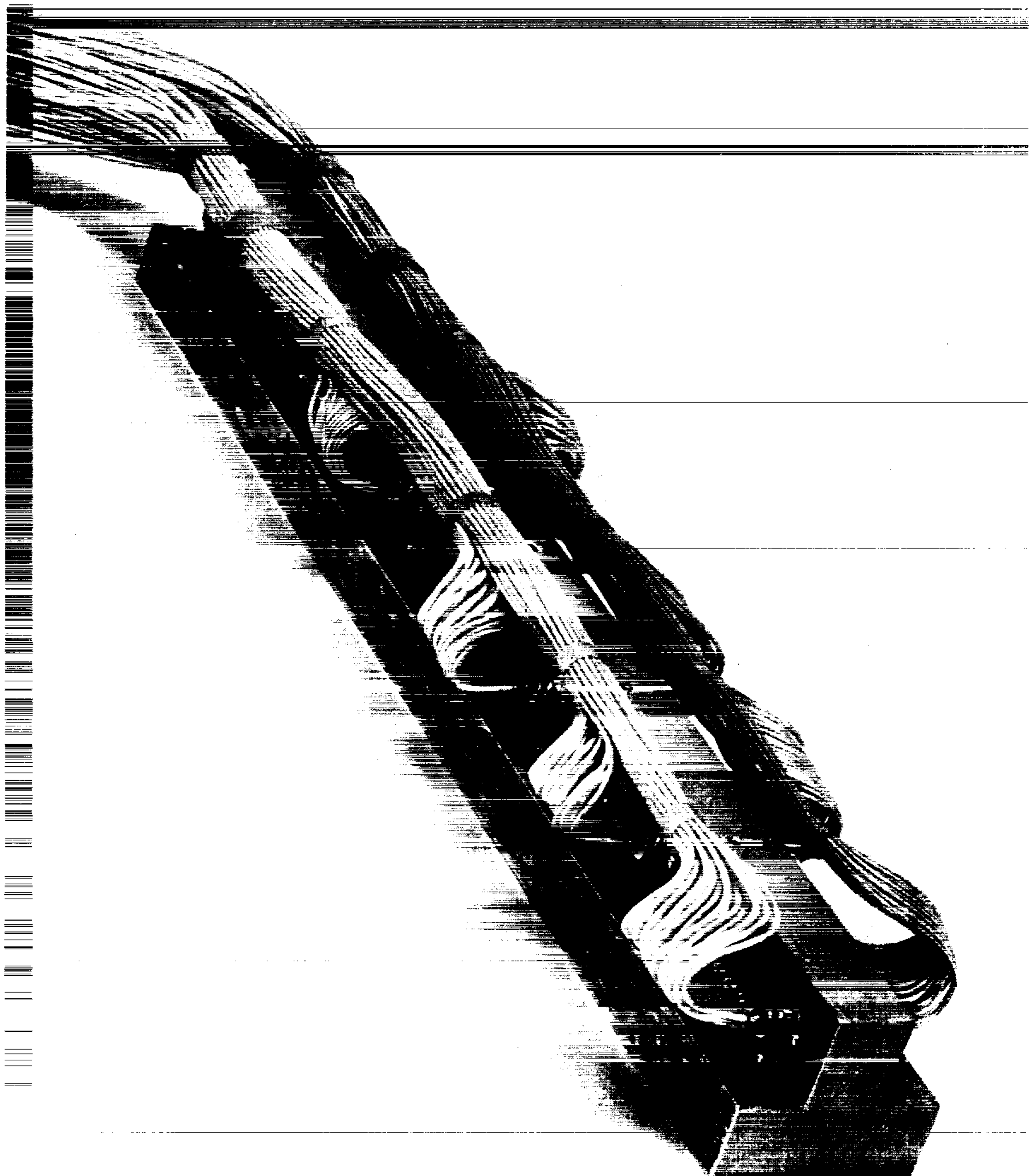

Fig. 4. Harnesses mounted on vibration fixtures

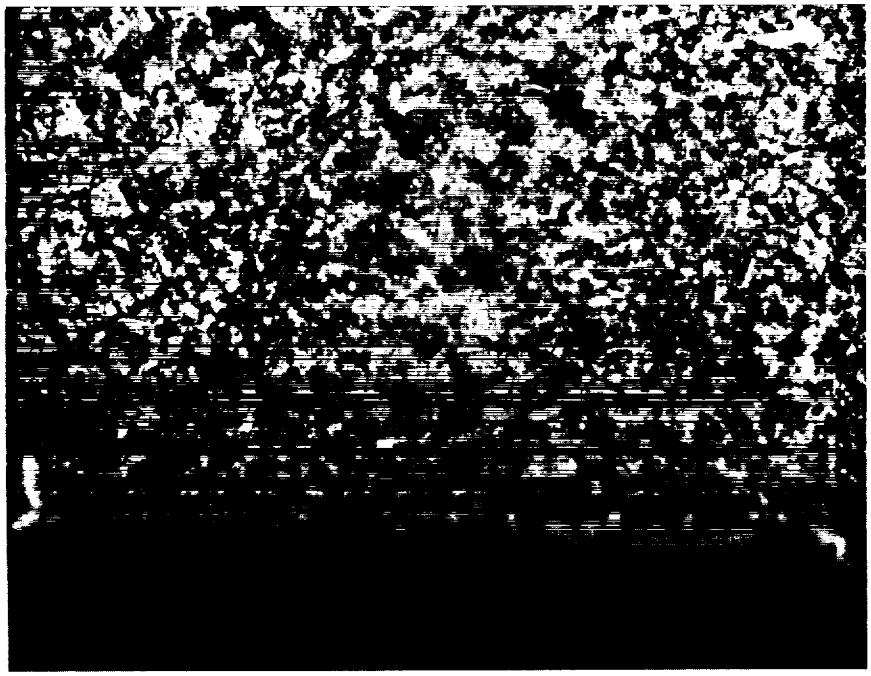

Fig. 5. Typical solder structure of solder in tinned and wicked solder joints in mechanically tested harness (magnification 1000×)

Fig. 6. Typical solder structure of solder in untinned and unwicked solder joints in mechanically tested harness (magnification 1000×)

NASA — JPL — Coml., L.A., Calif.