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ELECTRICAL TERMINATIONS:
WELDED, BRAZED, AND
BONDED, FY71-4

PDO 6984738, Quarterly Report

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ABSTRACT

Continued work on this project was devoted to development of in-process monitors, parallel-gap brazing of flexible copper circuit terminations, and evaluation of copper alloys. In-process monitors are being developed for opposed-electrode, parallel-gap, percussive-arc, and pulse-arc welding processes. Flexible copper test coupons are being used to develop a parallel-gap brazing process for electrical termination to component pins and flexible circuits. The evaluation of copper alloys is being conducted to determine the effect of bulk wire fabrication processes on oxygen content within the copper alloy, and the effect of this oxygen content on the pulse-arc welding process.

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SUMMARY

This development effort was begun in February, 1971, to improve the welding, brazing, and bonding processes required to make electrical terminations. Development activity is being concentrated in the areas of in-process monitoring equipment, modification of welding equipment, and manufacturing processes related to material control.

Previous activity was directed toward development of in-process monitoring equipment and brazeable, flexible copper circuit terminations. Prototype in-process monitors were built for applications on opposed-electrode, parallel-gap, percussive-arc and pulse-arc welding processes. Test coupons of eight different configurations were defined for use in developing a parallel-gap brazing process. These circuits were designed for termination to simulated component pins and to other flexible copper test coupons.

The percussive-arc monitor that is being developed will be capable of measuring arc time, peak current and impact velocity, which are the three important parameters that affect process control. The monitor provides a digital readout of the actual value of each of these parameters.

A percussive-arc power supply was modified to incorporate the necessary sensing circuitry for arc-time and peak-current measurements. This information is relayed to the percussive-arc monitor in the form of low-voltage signals. This modification allows the monitor to be isolated from the percussive-arc power supply, thereby eliminating the possibility of adversely affecting weld quality by electrical breakdown within the monitor.

The prototype pulse-arc monitor measures peak current and arc time, and digitally displays the values of each of these parameters. A current-viewing resistor (CVR) contained within the pulse-arc power supply is employed to derive a voltage proportional to the weld-current waveform. Circuitry is being developed to measure the weld current pulse in ampere-seconds, which is related to the energy of the delivered weld current integrated with time. If this parameter is correlated with process control, it will be incorporated into the prototype monitor.

An electrode-setdown monitor was completed during the previous fiscal quarter for application on opposed-electrode welding and positive correlation was established between process control and total deformation and penetration. A strain gage was incorporated to measure the movement of the weld electrodes during the weld sequence. The output of the strain gage is amplified, and a readout is visually displayed in milli-inches displacement. A new strain gage with approximately a 600-percent increase in sensitivity was built during the current quarter. Although this strain gage reduced the amount of amplification necessary, the required repeatability and accuracy

have not been achieved. Deflection of weld electrodes and electrode arms remains a variable that adversely affects the accuracy of measurement. The electronic circuitry involved is reliable, but additional investigation is required to determine the proper location for sensing the electrode movement during the weld sequence.

An rms-current monitor was developed for use on opposed-electrode and parallel-gap resistance welding processes. This system computes and digitally displays the rms value of the weld current from either a capacitor-discharge or ac-output weld system. The rms current level of the weld-current waveform is directly related to the amount of heat generated at the weld. As previously reported, the original prototype monitor digitally displays a current level that is not the true rms current at weld durations below 160 milliseconds. Circuitry was modified to yield true rms current levels at weld durations of 8.33 milliseconds and longer. This falls in the range of normal production weld schedules. The results obtained from this system are encouraging.

Development of a parallel-gap brazing process for terminating flexible copper circuits will be pursued throughout the course of this project. Flexible-circuit test coupons were fabricated for termination to simulated component pins and other flexible-circuit test coupons. Experiments with a silver/phosphorous/copper braze-alloy preform placed between the surfaces to be joined resulted in excellent braze terminations. With a flow temperature of approximately 1300°F and good wetting characteristics, this braze alloy offers potential for terminating flexible copper circuits with minimal copper damage. Electroless nickel plate will also be evaluated as a braze alloy. Test coupons plated with electroless nickel are being fabricated for that use.

Development of testing methods for determining oxygen content in various copper alloys is being conducted by the Materials Engineering Department. That work will include evaluation of process variables in bulk wire production in which oxygen can be diffused into the wire during the process of extruding insulation onto the wire.

Oxygen-free high-conductivity copper (OFHC) and electrolytic tough-pitch (ETP) copper were exposed to elevated temperatures in a dissociated ammonia atmosphere furnace. The ETP copper was severely embrittled, whereas the OFHC was affected very slightly. These results were verified by ASTM F-68 metallographic bend tests.

The status of the project conforms to the planned time schedule. Evaluation of the percussive-arc and rms-current monitors will be completed during the next reporting period, and will be incorporated into manufacturing a short time thereafter. The other terminating processes and the associated monitors will be evaluated further before production use.

DISCUSSION

SCOPE AND PURPOSE

This work is being conducted to establish in-process monitoring and material-preparation techniques necessary to yield consistent high-quality electrical terminations for a wide variety of part configurations. Some of the most critical of these are very small connector pins, thin-conductor flat cables, and microcircuit terminals. The work includes development of monitors for opposed-electrode, parallel-gap, percussive-arc, and pulse-arc welding systems for continuous production-line verification of the parameters that are pertinent to control of the process.

PRIOR WORK

The previously-reported work was principally devoted to design and construction of prototype in-process monitors for the four different welding methods and preparation of test coupons for development of a parallel-gap brazing process.

All of the monitors feature digital readout of the measured process parameters, which is not only of value in controlling the welding processes, but equally useful when establishing and troubleshooting weld schedules and when transferring established weld schedules from one welder to another of the same type.

The monitors for the opposed-electrode, parallel-gap, and percussive-arc welding processes were completed during the previous reporting period. Preliminary evaluation of these three monitors indicated that all were capable of providing the required process-control functions.

The prototype pulse-arc monitor was completed; however, it was necessary to install rf shielding within that unit to suppress spurious signal pickup which caused false responses. Modification of the pulse-arc monitor was started, but was not finished at that time; therefore, the feasibility of the design was not proven.

The test coupons for evaluation of a parallel gap brazing process consisted of eight different configurations required for tensile and peel tests. These specimens were made of 2-ounce, cold-rolled copper laminated to 3-mil Du Pont Kapton Film, and were designed for termination to other flexible-circuit test coupons and to simulated components pins.

ACTIVITY

Percussive-Arc Monitors

The percussive-arc monitor digitally displays the values of arc time, peak current, and impact velocity. These three variables directly affect process control on this welding process. The ability to ascertain the value of these variables during weld-schedule development, production welding, and troubleshooting process control difficulties is of significant value.

The initial design of this monitor required that weld energy be routed through the monitor for determination of arc time and peak current. A current-viewing resistor (CVR) is contained within the monitor and is connected in series with one of the weld energy leads. The voltage drop developed across the CVR is applied to a voltage memory card. The output of the voltage memory card is connected to a digital microammeter which indicates 0.1 microampere for each ampere of weld current. Since the ohmic value of the CVR is known, the voltage drop developed across it is easily converted to a digital readout of peak current.

The arc-time reference is a one-shot square-wave generator which is initiated by current through the air gap, and is stopped by the impact of the parts during the weld cycle. The reference square wave starts and stops an integrated-circuit counter which counts the pulses from a 100 kHz crystal-controlled oscillator. The output of the counter is displayed on a seven-segment digital indicator.

The one-shot square wave generator and CVR were incorporated within the Model 1000 percussive-arc power supply. This eliminated the need for routing weld energy through the percussive-arc monitor, and in turn eliminated the need for interconnecting weld-energy cables and four plug-in connectors. The only connections now required between the monitor and percussive-arc power supply are signal leads from the one-shot square-wave generator and the CVR.

The internal one-shot square-wave generator and CVR will be retained within the prototype percussive-arc monitor. By retaining these features, this system may be used on weld systems with or without the generator or CVR built into the power supply and will enable this monitor to be used on production welders that have not been modified.

Weld schedules were developed on eight material combinations used in production welding. Arc time, peak current, and impact velocity were measured with open-setup equipment. Arc time and peak current were measured with a current pulse transformer connected to a waveform-storage oscilloscope. Impact velocity was determined from a computerized curve which indicates velocity by comparing travel time of the moveable material versus distance traveled. Upon completion of the study of the eight different configurations, the open-setup method of determining weld parameters was paralleled by the prototype percussive-arc monitor. The optimum weld schedule for each combination of materials was re-evaluated with the monitor. There were no differences between the results obtained with the percussive-arc monitor and with the open-setup method.

A Hewlett Packard Model 3LV A5-N linear-voltage velocity transducer is used with the percussive-arc monitor for determining impact velocity. Basically, the transducer consists of an inductive coil and a moveable magnetic core. The output voltage is dependent upon the velocity of the magnetic core through the inductive coil. The normal range of velocities encountered in production welding is 40 to 70 inches per second. A calibration fixture is being constructed to verify that the transducer output is linear throughout the velocity range and to determine the actual output voltage per inch per second of velocity. This fixture system will drive the core at a known velocity and will allow calibration of the percussive-arc monitor velocity readout to match the output of the individual velocity transducer coupled to the monitor.

The prototype percussive-arc weld system with the modified Model 1000 power supply, signal cables, and monitor system is shown in Figure 1.

Electrode-Setdown Monitor

Electrode setdown, a phenomenon normally encountered in opposed-electrode welding applications, is defined as the total reduction in cross-sectional thickness at the weld termination that results from the combined deformation and penetration of the joined materials. This characteristic is a direct result of the applied electrode force and the short-duration, high-current weld energy.

An investigation conducted during the preceding reporting period revealed a positive correlation between electrode setdown and process control for opposed-electrode welding. Four different material combinations normally encountered in production were welded at various weld-energy settings.

The cross-sectional thickness of each specimen at the weld was measured and recorded. The strength of the weld bond was then determined by destructively testing each specimen. The results revealed a range of reduction in cross-sectional thicknesses which produced weld joints with visual and tensile properties acceptable for each material combination tested.

Figure 1. Percussive-Arc Model 1000 Power Supply and Prototype Percussive-Arc Monitor

The design of the electrode-setdown monitor shown in Figure 2 was based upon the data from that experiment.

A strain gage mounted on the weld head is used to sense electrode movement during the weld cycle. Since the output voltage of the strain gage is linear and proportional to displacement, the output can be connected to the setdown monitor, and the total displacement can be displayed digitally in thousandths of an inch. The output voltage of the strain gage is connected to a linear amplifier, the output of which is connected to a comparator circuit which compares the voltage at the beginning to that at the end of the weld cycle. The difference between the two voltages is applied to a digital voltmeter which provides a voltage-equivalent digital reading of electrode setdown.

Evaluation of this system during the previous reporting period indicated a need for improvements in three areas.

- The output of the strain gage was 1 millivolt per 0.001 inch displacement, which required considerable amplification to achieve a suitable voltage level.
- The structure used to support the strain gage was too light, resulting in an excessive "ringing" response during the measurement of setdown.
- Deflection of electrode holders and weld electrodes as a result of the applied electrode pressure was excessive.

A new strain gage was built of heavier support material. That gage produces an output voltage of 6 millivolts per 0.001 inch of displacement, which reduces the amount of amplification necessary, and also reduces the error potential by a factor of six. The previous strain gage required such a high degree of amplification that the amplifier was operating near the nonlinear region, and noise generated at the strain gage or at the amplifier level could adversely affect the accuracy of measurement.

Because of the low-inertia design of the weld head, minute expansion and contraction of the weld area is followed by the weld electrodes. This movement of the weld electrodes is coupled to the strain gage through the mounting brackets. The original strain gage was mounted on a 0.035-inch-thick aluminum bracket. The minute movement of the electrodes produced a vibration in the aluminum bracket which caused a sinusoidal waveform to be superimposed on the dc-voltage output of the strain gage. The strain gage output is sampled at the end of the weld cycle therefore, this superimposed sinusoidal voltage can result in an error signal as great as 0.005 volt and a setdown error as great as 0.005 inch.

Figure 2. Electrode-Setdown Monitor System

The new strain gage, with a thicker aluminum bracket (0.070 inch) and shorter length, eliminated the ringing problem and appreciably improved the accuracy of the setdown monitor. The problem related to displacement of the electrode arms and electrodes still adversely affects the readings that are obtained. A normal electrode pressure of 5 pounds is used to trigger the weld sequence. The pulse duration of the weld current is normally less than 12 milliseconds, during which time electrode pressure may increase at a rate dependent upon the rapidity of movement of the foot pedal that controls the weld-head movement. A relatively slow movement of the foot pedal from start to stop of the weld sequence produces the greatest degree of accuracy. A rapid thrust of the foot pedal produces an inaccuracy as great as 400 percent because of extremely rapid buildup in pressure during the sampling period at which the measurement is made. The higher the pressure achieved during the sampling period, the greater the deflection in electrode holders and weld electrodes, and the larger the degree of error.

A suitable mounting position for sensing the electrode-tip movement has not yet been determined. The movement of the electrode tips only, disregarding the flexing of electrodes and electrode holders, is the prime consideration in the successful development of this monitor. The method used to achieve this end must be compatible with production welding requirements in that it must not interfere with normal welding operation and replacement of weld electrodes. The reliability and accuracy of the electronics involved in this monitor have been established.

RMS-Reference Monitor

In resistance welding processes, short-duration, high-current weld energy is applied to the workpiece materials to create heat sufficient to create a weld bond. A determinant of the quantity of heat generated in these materials is the rms value of the current flowing through the weld junction. The major resistance in the output loop of a resistance welding system is that of the materials being joined. With the same weld current flow, any particular material combination will have relatively stable resistance from weld to weld. The rms value of the weld current is directly related to the heating effect of that current, and is a controllable function of any resistance welder. By monitoring the rms value of the weld current, a form of in-process verification can be obtained.

Evaluation of an rms current monitor that was built during the previous reporting period produced favorable results. Although correlation between the rms value of weld current and process control was verified with that system, the rms value indicated was not true rms for weld durations less than 160 milliseconds. However, acceptable weld schedules could normally be obtained with weld durations of 80 milliseconds or less.

Figure 3. Prototype RMS Current Monitor

Circuitry was developed to indicate the true rms current for weld durations as short as 8 milliseconds. This circuitry was incorporated into the rms current monitor. When used with a controlled ac welding power supply, the results were accurate and repeatable. The difference between the indicated current value and the true rms value was within 2 percent in all instances.

The circuit modification of this monitor consisted of replacing the Burr-Brown 4128 RMS-to-DC Converter with a Hallpak generator, a divider network, an integrator, and an amplifier.

The Hallpak generator produces a squared function of the input voltage, which is then integrated with respect to time. An amplifier is used to restore losses in the integrator. The output voltage from the amplifier is coupled to a voltage memory card, and from there to a digital millivolt meter. The indication on the digital meter is the true value $(\text{rms})^2 \times 10^{-4}$. The rms current monitor is shown in Figure 3.

The rms-current monitor will be evaluated with three types of resistance-welding equipment: a capacitor-discharge system, a phase-shift-controlled 60 Hz alternating-current system, and an amplitude-controlled 60 Hz alternating-current system. Only the amplitude-controlled ac system has been evaluated.

Pulse-Arc Monitor

The use of pulse-arc welded terminations requires that the materials to be joined be mechanically positioned in proximity to each other before welding is performed. This welding process produces a welded electrical termination that normally does not yield high physical strength. Physical strength is attained by mechanically staking or crimping the conductors together at a point or area close to the weld.

An in-process pulse-arc monitor is being developed for continuous monitoring of the parameters that directly affect process control. A prototype monitor which measures and digitally displays the value of peak current and weld duration in amperes and milliseconds was built during the preceding reporting period. Preliminary tests revealed that rf interference produced by the arc-initiation signal from the power supply resulted in erroneous indications. Shielding which effectively suppressed the rf interference has been installed since that time; however, because of the time required to complete that work, a full evaluation could not be completed before the end of the quarter.

Circuitry for measurement of weld energy in ampere-seconds was developed too late for evaluation during this quarter. If the information from evaluation of this circuitry correlates to process control, that circuitry will be included in the final design of the pulse-arc monitor.

Preliminary calibration of the ampere-second circuitry consisted of applying a square-wave voltage input and comparing the ampere-second digital reading to calculated values. The indicated values were all within 5 percent of the calculated values.

The parameters of weld power, weld energy, weld current, arc voltage, and arc resistance were studied to establish the general relationships of these parameters.

The following data were taken to provide a plot of the various parameters. These data were obtained by the use of polaroid photographs of the weld current and arc voltage for different welder control settings. Oscilloscope traces were recorded while varying one parameter and holding the others constant. The weld parameters which were varied included voltage, capacitance, pulse length, and materials.

The air gap between the tungsten electrode and piece-part materials was held constant throughout all evaluations. The materials welded were 0.125-inch diameter aluminum wire and 0.125-inch diameter copper wire. Data obtained from the oscilloscope traces were used to plot the following curves:

- Power versus time;
- Resistance versus time;
- Energy versus capacitance;
- Energy versus inductance; and
- Energy versus voltage.

Two methods were used to plot the curves. One method utilized a planimeter to mechanically integrate the waveforms; the other method involved dividing the waveform traces into incremental sections and then mechanically integrating.

Each of the curves was plotted with respect to a specific parameter variations.

- Power versus time was plotted while varying weld capacitance, weld voltage, and pulse length. All plots were made with 0.125-inch diameter copper wire. The power versus time curves and oscilloscope traces are shown in Figures 4 through 12. Figures 4, 5, and 6 represent the effects of changes in weld capacitance. The effects of changes in weld voltage are shown in Figures 7, 8, and 9. Figures 10, 11 and 12 represent the effect of changes in pulse length.

Text continues on page 36.

Figure 4. Power/Time Plot and Oscilloscope Trace, Coarse Capacitance 2

Figure 5. Power/Time Plot and Oscilloscope Trace, Coarse Capacitance 5

Figure 6. Power/Time Plot and Oscilloscope Trace, Coarse Capacitance 7

Figure 7. Power/Time Plot and Oscilloscope Trace at 50 Volts

Figure 8. Power/Time Plot and Oscilloscope Trace at 60 Volts

Figure 9. Power/Time Plot and Oscilloscope Trace at 70 Volts

Figure 10. Power/Time Plot and Oscilloscope Trace, Pulse Setting 1

Figure 11. Power/Time Plot and Oscilloscope Trace, Pulse Setting 2

Figure 12. Power/Time Plot and Oscilloscope Trace, Pulse Setting 3

- Arc resistance versus time plots were made at two different voltage settings with two different materials. One material was 0.125-inch diameter copper; the other was 0.125-inch diameter aluminum. Figures 13 and 14 represent the plotted curves and oscilloscope traces for two different voltage settings for 0.125-inch diameter aluminum wire. Figures 15 and 16 show the plotted curves and oscilloscope traces for the 0.125-inch copper wire with the same applied voltages.
- The energy versus capacitance curve (Figure 17) was made by plotting the actual energy versus capacitance curve. This curve and oscilloscope trace is shown in Figure 18.
- The energy versus voltage curve (Figure 19) was plotted in the same manner used for the two preceding plots.

All of the welds were made with a Model 300B pulse-arc power supply connected to 0.125-inch diameter conical-pointed tungsten electrodes. All tests were performed with an argon cover gas.

The results of this investigation were as follows.

- Arc resistance varied only slightly with different voltage settings and materials.
- Power dissipated in the weld varied dependent upon variations in pulse width, voltage, and capacitance.
- Because of internal losses within the welder switching circuits and power cables the theoretical power was always greater than the actual energy dissipated in the arc.

Text continues on page 44.

Figure 13. Resistance/Time Plot and Oscilloscope Trace, Al Wire, 50 Volts

Figure 14. Resistance/Time Plot and Oscilloscope Trace, Al Wire, 70 Volts

Figure 15. Resistance/Time Plot and Oscilloscope Trace, Cu Wire, 50 Volts

Figure 16. Resistance/Time Plot and Oscilloscope Trace. Cu Wire, 70 Volts

Figure 17. Energy/Capacitance Plot, Cu Wire, 50 Volts

Figure 18. Energy/Inductance Plot, Cu Wire, 50 Volts

Figure 19. Weld Energy Versus Supply Voltage for 0.1285 Copper

Parallel-Gap Brazing

Flexible copper test coupons are being fabricated for use in developing a parallel-gap brazing process. The flexible copper test coupons are made from 2-ounce, cold-rolled copper stock laminated between 3-mil Du Pont Kapton insulation. The first lot of these coupons was completed during the previous reporting period; however, the coupons were not used in tests of the welding process at that time. Inspection of those coupons indicated a need for more complete removal of the adhesive from the terminal areas.

Tests were conducted during this reporting period on several stripping solutions to determine a more effective means of removing epoxy adhesives from the termination areas of the flexible circuits.

Of the methods tried, concentrated sulfuric acid at 160°F, was the most effective solution for that purpose; however, further improvement is necessary.

Several lamination trials were conducted to determine the cause of voids along the individual conductors between the base film and the cover layer. These voids were eliminated by the use of an improved pressure pad on the laminating press.

Additional unplated test coupons are required for use in evaluation of parallel-gap brazing with a copper/phosphorous/silver braze alloy. These coupons are processed through the destressing operation and will be completed during the next reporting period.

A third series of flexible copper test coupons was started for use in evaluating electroless nickel plating as a braze alloy. These coupons will be plated on one side of the exposed copper conductors with electroless nickel in thicknesses of 100 to 200, and 200 to 300 microinches. The phosphorous content will range from 4 to 7 percent, and each plating bath will be tested to determine the actual phosphorous content. Since the phosphorous content of electroless nickel plate affects the melting temperature of the alloy, the exact content must be known. A phosphorous content of 5 percent by weight yields a melting temperature of approximately 1250°F. A phosphorous content of 12 percent by weight melts at approximately 1814°F. These coupons will be available for parallel-gap brazing evaluations during the next reporting period.

Investigation of a copper/phosphorous/silver braze alloy as a terminating medium was initiated by Materials Engineering during this reporting interval. This braze material contains 15-percent silver, 5-percent phosphorous, and 80-percent copper. The phosphorous acts as a flux during the brazing cycle. This braze alloy melts at approximately 1185°F and flows at approximately 1300°F. The latter temperature is sufficiently below that of copper (1980°F) to allow a wide range of joining schedules.

This alloy is covered by Mil QQ-B-655, and is produced under numerous trade names such as Sil-Fos 15 (Handy and Harmon), Phoson 15 (United Wire), and Silvaloy 15 (American Platinum Works).

Test joints produced on lap-brazed, flat copper conductors can be brazed by the parallel-gap or by the opposed-electrode process. A precut braze preform is placed between the copper conductors and is melted to produce the braze bond. Since tungsten electrodes are used, current flowing through the resistance of the tungsten causes the tips to heat. Therefore, the heat transferred from the electrodes to the braze joints adds to that produced by the resistivity of the joint. Test specimens brazed into tensile-shear and tensile-peel configurations were destructively tested. All failures occurred in the parent material.

An easy method of applying the braze material to the joining surfaces was developed. Since the braze alloy does not wet tungsten, this property was used in a premelting operation. Tungsten electrodes and the parallel-gap brazing process were employed to premelt the braze alloy preforms to the fusing surface on one of the two copper specimens to be joined (Figure 20). The parallel-gap process was then used to remelt the braze alloy, thereby completing the brazed joint. All test joints brazed in this manner produced satisfactory strengths.

A 110-volt, Bendix-designed 1 kVA ac power supply was used in conjunction with a Hughes Model VTA-76 parallel-gap weld head throughout these experiments. The controlled-amplitude power supply yields a linear increase in power and allows accurate control of weld current and duration. All braze configurations had reasonably wide ranges of welder control settings and yielded satisfactory results. Peak weld current and weld duration were monitored throughout all of the tests to assure repeatability in later tests.

A weld schedule was developed on lap joints of 0.080-inch-wide by 0.0025-inch-thick OFHC copper flexcircuits with the copper/silver/phosphorous braze alloy.

Specimens were brazed into tensile shear and tensile peel test specimens (Figure 21). All braze joints tested failed by fracturing the copper specimen, not the braze joint. Variation in the braze preform size had little effect upon joint quality, and appeared to affect only the amount of braze material expelled from the joint. Using the criteria of expelled braze metal, the 0.06- by 0.02- by 0.003-inch braze preform was considered best. Metallurgical evaluation of these joints shows a metallurgically sound, uniform braze joint (Figure 22).

A. Unmelted Braze Preform

B. Premelted Braze Preform

C. Tensile Fractured Joint

D. Peel Fractured Joint

Figure 20. Parallel-Gap Joints Brazed With Braze Preforms, 10X

A. Copper Flexcircuit 0.08-inch Wide by 0.0025-inch Thick at 50X (Left) and 500X (Right)

B. Copper Flexcircuit 0.06-inch Wide by 0.0025-inch Thick at 50X (Left) and 500X (Right)

Figure 21. Typical Parallel-Gap Braze Joints on Ferric Chloride-Etched Copper Flexcircuits

A. ETP Copper As-Received

B. ETP Copper After Heating

C. OFHC Copper As-Received

D. OFHC Copper After Heating

Figure 22. Metallographic Structure of ETP and OFHC Copper at 100X

A similar schedule was developed on lap joints of 0.060-inch-wide by 0.0025-inch-thick copper flexcircuits. The pull-test results were identical to those of the previous specimens. The only difference was that the optimum preform size was 0.004 by 0.02 by 0.003.

Braze dipping was attempted as a method of applying the braze material. Under cover of argon gas, the circuit termination area was dipped into a small crucible of molten copper/silver/phosphorous braze material. Initially, the braze material wetted the circuits very well, but the wetting ability of the braze material soon became very poor. It was concluded that phosphorous evaporates from the alloy, decreasing its wetting ability and its usefulness.

An ultrasonic lead bonder is being considered as a possible means of applying the braze material. A source of 3-mil-diameter copper/silver/phosphorous braze wire (required for the lead bonder) has been found. The ultrasonic lead bonder will be used to bond small tabs of wire to the faying surface. If this process is successful, it will simplify the placement of braze preforms.

A corrosion study was conducted by the Materials Engineering group to determine if the presence of phosphorous in the alloy contributes to corrosion in the braze joint. A representative number of weld specimens from each of the above-mentioned schedules were exposed to the corrosive environment described in Mil Std 202, Method 106 (humidity test to simulate a tropical environment). Joint strengths after exposure were not affected. Visual inspection revealed no more corrosion on the test joints than on other areas.

An investigation was conducted to determine the feasibility of terminating copper flexible circuits to copper printed circuit boards. The flexcircuit specimens were 0.040-inch wide by 0.0025-inch thick. The circuit-board paths were 0.040-inch wide by 0.002-inch thick, and were laminated to FR-45 substrate. A copper/silver/phosphorous braze preform was premelted to the flexible circuit, and the circuit was then brazed to the board. The pulse length was minimized to 3-1/2 cycles to reduce heat damage to the board. These joints were destructively tested in 90-degree peel. All failures occurred between the paths and the boards. Metallurgical examination revealed uniform, metallurgically sound braze joints.

The amount of braze material used for the printed circuit board experiment was more critical than on regular lap welds between flexible circuit ribbons. In this application, the expelled braze material can bridge the gap between individual circuit paths, thereby producing short circuits. For that reason, the braze preform size was limited to 0.020 by 0.010 by 0.003 inch.

Preliminary investigation of the effects of gold plating on the metallurgical bond between the copper flexible circuits and gold-plated copper-clad circuit boards revealed that all destructively-tested copper/silver/phosphorous alloy braze joints failed between the circuit-board paths and the board laminate. However, metallurgical inspection revealed that this braze alloy does not wet the gold as well as it wets bare copper. Because of that condition, evaluation of this alloy for brazing to gold-plated materials will be continued.

A silver/copper/lithium braze alloy is being considered for brazing applications which have a gold-plated faying surface. This alloy consists of 71.5-percent silver, 28-percent copper, and 5-percent lithium. The lithium provides a self-fluxing effect; therefore, this alloy may prove more effective than the phosphorous alloy when used on gold-plated surfaces.

Braze preforms are now being precut from copper/silver/phosphorous and silver/copper/lithium flat stock for evaluation by brazing flexible copper circuits to simulated component pins of beryllium copper, Kovar, Alloy-52, and phosphor bronze. These pins, both unplated and gold plated, will be evaluated with each of the two braze alloys. The wetting capability of the silver/copper/lithium braze alloy is to be evaluated and compared to that of the copper/silver/phosphorous alloy.

Copper-Alloy Evaluation

Evaluation of hardware configurations for pulse-arc welding was started to better define those materials which can be acceptably pulse-arc welded. An initial portion of this study is to evaluate various copper alloys and the effect that production processes have on the weldability of these alloys. This experiment will aid in determining the relative weldability of various copper alloys, and will develop testing procedures to verify that the materials received for future production welding meet the requirements of the applicable wire specifications involved. With this experiment it will also be determined if oxygen and hydrogen diffuse into the copper alloys as a result of processing the metal into insulated wire and subsequent fabrication processes at Bendix. This investigation will be supported by the Materials Engineering Department. The specimens that will be evaluated are described as follows.

Materials:

Oxygen-free high-conductivity (OFHC) copper, CDA102;

Phosphorous deoxidized low residual phosphorous (DLP) copper, CDA109;

Boron deoxidized (BD) copper, CDA109; and

Electrolytic tough-pitch (ETP) copper, CDA110.

Coatings:

Nickel plating 50 to 100 microinches; and

Bare copper.

Sizes:

Round wire, 12 AWG and 34 AWG, 0.080 and 0.0063 diameters; and

Flat ribbon, 0.081 by 0.250 and 0.005 by 0.250.

Conditioning:

The specimens will be conditioned before testing in an air circulating oven at the temperatures and for the times listed in Table 1.

Table 1. Specimen Numbering and Conditioning

Temperature	Specimen Numbers*	
	Conditioned in Air for 30 Minutes	Conditioned in Air for 4 Hours
150°C (320°F)	1a and 3a	2a and 4a
250°C (482°F)	1b and 3b	2b and 4b
350°C (662°F)	1c and 3c	2c and 4c
450°C (842°F)	1d and 3d	2d and 4d
550°C (1022°F)	1e and 3e	2e and 4e
650°C (1202°F)	1f and 3f	2f and 4f
750°C (1382°F)	1g and 3g	2g and 4g
Room Ambient	1h and 3h	2h and 4h
*After conditioning, specimens 3 and 4 will be heated in a reduced atmosphere (10-percent hydrogen, minimum) for 30 minutes at 850°C (1562°F).		

The specimens will be tested as follows.

Bend Test:

A 300 psi tensile load will be applied to one end of the specimens, while the other is held in a clamp fixture. The jaws of the holding fixture will be machined to an edge radius of 2-1/2 times the diameter of the wire or the thickness of the ribbon. The specimen will be bent 90 degrees, then back to the original position, each cycle of which will constitute one bend. The bending will be repeated, first in one direction and then in the other, until the specimen fails. The number of bends before failure will then be recorded.

Metallographic Examination:

Longitudinal specimens will be mounted, polished, etched, and examined at 100X and 400X magnifications. Photomicrographs will be made at 40X and 100X magnifications.

Welding Evaluation:

Copper wire samples will be prepared as facsimiles of production-welded configurations. These will be welded by the pulse-arc process. These weld specimens will be mounted, polished, etched, and evaluated at 25X to 50X magnification. Photomicrographs will be made at 25X.

All materials listed have been received or are on order.

A preliminary study was made to determine if the dissociated ammonia atmosphere furnace in the heat treating and carbonizing facility is suitable for performing the hydrogen embrittlement tests specified in ASTM F-68. Theoretically, this furnace will produce an atmosphere consisting of 75-percent hydrogen and 25-percent nitrogen, by volume. This is the only furnace with a controllable atmosphere containing more than 10-percent hydrogen that is available at Bendix.

Three specimens (0.125-inch diameter by 3 inches long) each of electrolytic tough-pitch copper (ETP) and oxygen-free, high-conductivity copper (OHFC) wire were subjected to bend tests and metallographic examination both before and after heating in the dissociated ammonia atmosphere at 850°C (1562°F) for 30 minutes and oil quenching. The bend test was performed as described in ASTM F-68. In this test the specimens were bent 90° around a radius rod equal to 2-1/2 times the diameter of the wire and then returned to their original positions; this constituted one bend. Each successive bend was made in the opposite direction. Metallographic specimens were mounted, polished, etched, and examined. Bend test

results are summarized in Table 2 and photomicrographs of the microstructures are shown at 100X, 200X, and 400X magnifications in Figures 22, 23, and 24, respectively.

The hydrogen embrittlement test is used to differentiate between oxygen-bearing coppers such as ETP copper and oxygen-free coppers such as OFHC copper. ETP copper normally contains approximately 0.03- to 0.07-percent oxygen as cuprous oxide (Cu_2O). The cuprous oxide is normally distributed throughout the structure as small elongated inclusions in a matrix of copper grains. When ETP copper is heated in a reducing atmosphere that contains hydrogen, the hydrogen reacts with the cuprous oxide to form steam. The pressure caused by the steam literally blows the copper apart, causing visible separations at the grain boundaries and consequent embrittlement of the copper.

The bend tests results given in Table 2 show that the ETP copper was severally embrittled by heating in the dissociated ammonia atmosphere and that it failed during the first bend, whereas the OFHC copper was only slightly affected and withstood 9 to 12 bends.

Table 2. Bend-Test Data

Type of Copper	Number of Bends to Failure	
	As-Received Condition	Heat Treated*
ETP (Oxygen Bearing)	10, 11, 13	0, 0, 0**
OFHC (Oxygen Free)	14, 17, 17	9, 10, 12
*After heating for 30 minutes at 850°C (1562°F) in a dissociated ammonia atmosphere and oil heating.		
**Specimens broke on first bend.		

As shown in the photomicrographs in Figures 22, 23, and 24, the as-received ETP copper contains numerous elongated cuprous-oxide (Cu_2O) inclusions. After heating in the dissociated ammonia atmosphere, numerous voids are present along the grain boundaries of the ETP copper. The OFHC was unaffected by heating in dissociated ammonia except for an expected increase in grain size.

This study proved that the dissociated-ammonia-atmosphere oven which is now at Bendix is suitable for performing hydrogen embrittlement tests. That test proved suitable for determining oxygen content in copper alloy wire.

Text continues on page 56

A. ETP Copper As-Received

B. ETP Copper After Heating

C. OFHC Copper As-Received

D. OFHC Copper After Heating

Figure 23. Metallographic Structures of ETP and OFHC Copper at 200X

A. ETP Copper As-Received

B. ETP Copper After Heating

C. OFHC Copper As-Received

D. OFHC Copper After Heating

Figure 24. Metallographic Structures of ETP and OFHC Copper at 400X

ACCOMPLISHMENTS

Percussive-Arc Monitor

A current-viewing resistor (CVR) and a square-wave generator were successfully installed in the Model 1000 percussive-arc power supply. Use of that supply with the prototype percussive-arc monitor produced satisfactory results; however, a full evaluation of the system will be conducted before adopting this method for manufacturing operations.

Electrode-Setdown Monitor

Installation of an improved higher-output strain gage and heavier strain-gage mounting brackets reduced the "ringing" effect in the strain-gage output. Although the electronic circuitry of this monitor is satisfactory, the desired accuracy has not been obtained because of deflection of the weld electrodes and the electrode holders.

RMS-Reference Monitor

The Burr-Brown Model 4128 rms-to-dc converter was replaced with a Hallpak generator, a divider network, an integrator, and an amplifier to provide true rms weld current indications. Evaluation of this system with an amplitude-controlled ac-output power source produced true rms weld-current readings for weld durations as short as 8.3 milliseconds.

Pulse-Arc Monitor

Because of the time required to install the rf shielding in the pulse-arc monitor, no tests were conducted under actual welding conditions. Circuitry developed for measurement of ampere-seconds will be installed in the pulse-arc monitor if correlation of that parameter to process control can be verified. Weld energy, weld current, arc-voltage, and arc resistance also were investigated to establish the relationships of those parameters to the pulse-arc welding process. Results were as expected: Arc resistance varies only a small amount with changes in materials and weld voltage; the power dissipated is dependent upon pulse width, voltage, and capacitance; and, because of power losses in the cables and internal resistance of the welder, theoretical power (as provided by the source) is always greater than the energy that is actually dissipated in the weld.

Parallel-Gap Brazing

Of several stripping solutions used to remove the epoxy adhesive from the terminal areas of the flexible copper/Kapton laminated test coupons, a concentrated sulphuric acid at 160°F was the most satisfactory.

Use of fiberglass-reinforced inflatable pressure pads in the laminating press provided more-uniform pressure distribution, thereby eliminating voids between the base film and the cover layers of the specimens and improving the overall appearance.

Fabrication of test coupons for further evaluation of copper/phosphorous/silver braze preforms was begun; however, these specimens were not available for evaluation during this fiscal quarter. Electroless nickel-plated test coupons also are to be fabricated to evaluate the use of electroless nickel as a brazing material.

Copper/phosphorous/silver alloy preforms were used to produce parallel-gap brazed lap joints between flat copper conductors. Peel and tension tests of these specimens revealed excellent bond strengths. Use of these preforms in brazing flat copper conductors produced bond strengths greater than that of the weaker joined material. Metallographic cross-sections revealed a tendency toward incomplete wetting of the gold-plated surface, a phenomenon which will be investigated further.

Positioning the small braze-alloy preforms on small terminating surfaces is difficult. Premelting the preform onto the faying surface of one of the conductors before brazing helped to alleviate this problem; however, further improvement is necessary to enable braze performs to be used successfully on small production assemblies.

Copper-Alloy Evaluation

Four different copper alloys will be evaluated to determine the effect of processes related to the manufacture of wire upon the metallurgical properties of these alloys and pulse-arc welding process. The result of this evaluation should yield a better understanding of the effects of oxygen content within the wire on pulse-arc weld quality and will establish a method of testing for oxygen content in the as-received wire condition. Four copper alloys will be evaluated in four different configurations in unplated and nickel-plated conditions. The four alloys are electrolytic tough-pitch (ETP) copper, oxygen-free high-conductivity (OFHC) copper, phosphorous-deoxidized, low-residual-phosphorous (DLP) copper, and boron deoxidized (BD) copper.

A study was completed to determine if a dissociated ammonia atmosphere furnace in the heat treating and carbonizing facility is satisfactory for performing a hydrogen embrittlement test as specified by ASTM F-68. The oven proved satisfactory, and the results of this evaluation proved the feasibility of performing a hydrogen embrittlement test for determining relative oxygen content in copper alloys.

FUTURE WORK

Percussive-Arc Monitor

Activity will be directed towards completion of equipment required to calibrate the linear voltage transducer used to determine impact velocity. Materials required to fabricate this equipment were ordered. Assembly and evaluation will be completed during the next reporting period.

Electrode-Setdown Monitor

Modifications of electrode holders and weld electrodes to reduce deflection are in progress. Improvements in location of the strain gage transducer will be evaluated to determine the best location to improve the accuracy of this monitor system.

RMS-Reference Monitor

The rms monitor will be fully evaluated on phase-shift controlled alternating current output and capacitor discharge weld systems. Weld current waveforms will be mathematically integrated to determine the true rms value on the monitor. Weld schedules will be developed, transferred, and reset into the weld systems evaluated.

Pulse-Arc Monitor

The prototype pulse-arc monitor will be evaluated under actual welding conditions to determine the effect of the parameters of peak current and weld duration upon process control. The ampere-second circuitry also will be evaluated under the above-mentioned conditions. Various material combinations will be welded at acceptable and unacceptable welder control settings to determine the ability of the monitor to detect out-of-control conditions.

Parallel-Gap Brazing

Continued evaluation of copper/phosphorous/silver braze alloy on flat copper conductors to flat copper conductors will be pursued during the next reporting period. Flexible copper circuit terminations to simulated component pins of Alloy 52, beryllium-copper, Kovar, and phosphorous bronze will be evaluated with this braze alloy.

Silver/copper/lithium braze preforms will be evaluated as a braze medium on terminations to gold-plated component pins. Initial tests of electroless nickel-plated test coupons will be initiated as soon as they become available.

Accoustic-Emission Study

Although those objectives noted in the last quarterly report will be completed, no additional activity is planned for the immediate future.

Copper-Alloy Evaluation

The four copper alloys listed in this report will be studied during the next reporting period. This investigation will include conditioning the copper alloys in an air circulating oven, followed by conditioning in a reducing atmosphere of 10-percent minimum hydrogen. After conditioning, these specimens will be subjected to bend testing, metallographic examination, and pulse-arc welding evaluation. The pulse-arc weld evaluation will consist of assembling terminations similar to those used in production, developing weld schedules, welding at an acceptable weld schedule, and metallographic examination.