ULTRASONICALLY WELDING ELECTRIC
TERMINALS

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ULTRASONICALLY WELDING ELECTRIC TERMINALS

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Prepared by G. S. Darner, D/862, under PDO 6984910

The ultrasonic welding of electrical terminations is being investigated for use on foil conductor terminations. Cleaning, surface finish, and plating were evaluated to determine their effects on ultrasonic weldability. The external application of heat was studied to observe any improvement in material weldability. Capabilities were established for welding two circuit layers separated by Mylar insulation and for terminating aluminum conductors to connector hardware.

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SUMMARY

Ultrasonic welding requires minimal surface preparation, but even the more readily weldable materials such as aluminum and copper require the removal of surface lubricants. Utilizing trichloroethylene as a degreasing agent, ultrasonic cleaning, spray cleaning, and wiping were evaluated for their effectiveness. All three methods were found to be equally effective for removing oils from the material surface.

To evaluate the effects of surface finish on ultrasonic weldability, copper and aluminum foils were ultrasonically welded to aluminum test plates with varying surface finishes. Surface finish variations were found to have minimal effect on these materials.

The effects of plating on the ultrasonic welding process were studied since plated materials are often encountered in production. Examination of welds made on nickel and gold plated copper foils showed that high quality welds can be made between plated materials.

The capability to weld two circuit layers separated by Mylar insulation has been developed. By heating the welder anvil and statically clamping the workpiece between the Sonotrode and anvil, the Mylar can be melted and forced from the weld area. The two circuit layers are then ultrasonically welded.

The external application of heat to materials being ultrasonically welded was studied to see if this technique would improve material weldability. Material combinations that were previously certified at ambient temperatures were welded at elevated temperatures and then pull tested. The results, as compared to the original certification data, showed a slight improvement in weldability and strength at 150°F (65.5°C). However, the benefits derived are offset by the disadvantages of handling hot materials and by reduced system efficiency.

Ultrasonic ring welding, a process utilizing torsional rather than linear motion, was evaluated for welding foil conductors to small eyelets. Ultrasonic ring welding proved to be ideal for this application and provides a technique for ultrasonically welding many circular configurations.

Ultrasonic welding provides the capability for joining aluminum foil conductors directly to connector hardware, eliminating the need for transitional joints previously required by other forms of welding. Simulated removable contacts and connector shells have been ultrasonically welded to aluminum foil conductors. Since most connector contacts are fabricated from beryllium copper, techniques were developed to overcome the significant material hardness mismatch which previously prevented the ultrasonic welding of this material.

DISCUSSION

SCOPE AND PURPOSE

The object of this project is to establish the process capability for ultrasonic welding material combinations and configurations that cannot be successfully joined with other welding processes. Ultrasonic welding is especially useful for the termination of flat aluminum conductors. Material combinations, weld configurations, and equipment requirements are being investigated for future production use.

PRIOR WORK

Prior work^{1,2} included selection of welding equipment, equipment evaluation and modification, sonotrode and anvil design, system monitoring, weld schedule and certification method development, certification of several material combinations, environmental testing, evaluation of material considerations and a study of frequency relationships.

ACTIVITY

Pre-Weld Cleaning

Surface cleaning in preparation for ultrasonic welding is not highly critical for most materials. The ultrasonic welding mechanism disrupts and disperses normal oxide layers and other surface films on the mating surfaces. The more readily weldable materials, such as aluminum and copper, usually require only the removal of surface lubricants. However, a few materials, such as heat treated metals and heavily oxidized materials, may require mechanical abrasion.

Evaluations were performed to determine the suitability of three methods for the removal of surface lubricants. Using trichloroethylene as a degreasing agent, ultrasonic cleaning, spray cleaning and wiping were studied. Samples of ETP Copper Alloy 110 (0.027 inch or 0.0686 mm thick) were coated with oil to represent a worst case condition. Some of the samples were cleaned by each of the three methods while a control group remained uncleaned. At a constant weld schedule setting, samples from all four groups were ultrasonically welded and then pull tested. The welds made on the cleaned materials were of high quality, regardless of the cleaning method. The uncleaned control samples could not be welded. Since all three methods are equally effective in removing surface lubricants, the choice of cleaning method can be based on the size and configurations of the parts to be welded.

Surface Finish Effects

During past evaluations, rolled, extruded, and drawn surface finishes were found to be satisfactory as received for ultrasonic welding. However, since machined surfaces are often encountered on production piece parts, a study was made to determine the effects of material surface variations on ultrasonic weldability.

Sample test plates fabricated from 0.125 inch (3.17 mm) 7075-T6 aluminum were finished to roughness heights of 8, 16, 32 and 63 microinches (203, 406, 813, and 1600 nm). ETP Copper Alloy 110 (0.0027 inch or 0.0686 mm thick) samples were welded to the test plates at a constant weld schedule setting and destructively pull tested. The resulting welds to all of the finishes were of high quality and all exhibited similar pull strength. This test was then repeated by welding Aluminum Alloy 1100-H19 foil (0.002 inch or 0.051 mm thick) to the test plates. The resulting welds were also of this quality.

Surface finish had no apparent effect on the weldability of these materials. Piece parts do not require special surface preparation or tolerancing. Most machined surfaces encountered on production parts fall in the roughness range evaluated.

Plated Materials

Since plated materials are often encountered in actual production applications, an evaluation was undertaken to determine the effects of ultrasonic welding on plated materials. For this investigation, samples of ETP Copper Alloy 110-Hard T (0.0053 inch or 0.1346 mm thick) were gold plated in accordance with Process Standard 9902112, Type 2, Class 2. Samples of the same material were also nickel plated in accordance with Process Standard 9902105.

A weld schedule was developed for the gold plated copper welded to itself and sample welds were destructively pull tested and metallurgically examined. The weld joint was formed between the two layers of gold, with no disruption of the gold plating (Figure 1). The welds were metallurgically sound and exhibited an average pull strength of 10.08 pounds (4.57 kg).

The nickel plated copper material was welded to itself and sample welds were again pull tested and metallurgically cross-sectioned. With this material combination, the nickel plating was disrupted and most of the weld joint was a copper-to-copper weld. However, these welds were also metallurgically sound. Figure 2 shows the nickel plating dispersion at the edge of the weld area. No plating is visible at the center of the weld area, which is out of the picture to the left.

Figure 1. Gold Plated Copper To Gold Plated Copper

Figure 2. Nickel Plated Copper To Nickel Plated Copper

Plating appears to be no hinderance to the ultrasonic welding process. Although two types of bonding phenomena were observed, both produced good welds. The occurrence of one type of bonding over the other is seemingly related to the weldability of the plating material used.

Welding Through Mylar Insulation

Because of increased usage of multi-layer flexible circuitry, the capability was developed to ultrasonically weld two circuit layers separated by Mylar insulation. The approach taken was to melt the Mylar between the circuit layers and force it from the weld area by the static clamp force applied by the ultrasonic welder. Once the Mylar was removed from the weld area, an ultrasonic termination was made between the circuit layers.

A special welding set-up was devised to melt the Mylar (Figure 3). A heat insulating anvil shaft was fabricated from machinable ceramic. A thermocouple was welded to a standard anvil tip and threaded onto the top of the insulating shaft. A 125-watt band heater, attached to the anvil assembly, was regulated by temperature feedback control circuitry. A digital readout monitored the temperature of the anvil.

Experimentation proved 600°F (315.5°C) to be the optimum temperature for this process. After clamping the weld material between the Sonotrode (Sonobond Corporation, West Chester, PA) and anvil, it is held for several seconds for the Mylar to be melted and forced from the weld area. The actual time required is dependent on the weld configuration, material combination, and material thickness. Once the Mylar is displaced from the weld area, metallurgically sound ultrasonic welds are produced between the circuit layers.

Three material combinations were evaluated during investigation of this procedure:

- Aluminum Alloy 1100-0 (0.004 inch or 0.102 mm thick) to Aluminum Alloy 1100-0 (0.0005 inch or 0.0127 mm thick) separated by two 0.005 inch (0.127 mm) layers of Mylar,
- Aluminum Alloy 1100-0 (0.005 inch or 0.127 mm thick) to annealed ETP Copper Alloy 110 (0.005 inch or 0.127 mm thick) separated by 0.010 inch (0.254 mm) of Mylar, and
- Annealed ETP Copper Alloy 110 (0.005 inch or 0.127 mm thick) to annealed ETP Copper Alloy 110 (0.005 inch or 0.127 mm thick) separated by 0.010 inch (0.254 mm) of Mylar.

Figure 3. Special Welding Setup

Figure 4 shows a cross section of an ultrasonic weld between the 0.004 inch (0.102 mm) aluminum and the 0.0005 inch (0.0127 mm) aluminum separated by two 0.005 inch (0.127 mm) layers of Mylar. The weld quality is good and all Mylar has been displaced from the weld zone. The welds made between the other material combinations exhibit the same high quality as the one shown.

Hot Ultrasonic Welding

Hot ultrasonic welding involves the external application of heat to the materials being welded in order to increase molecular activity in the materials and thus theoretically increase their weldability. To evaluate this procedure, several material combinations, previously certified at ambient temperatures, were welded at elevated temperatures and the resulting data were compared to the original certification data.

Figure 4. Cross Section of Ultrasonic Weld Through Mylar Insulation

The welding setup previously employed in the studies of welding through Mylar insulation (Figure 3) was utilized to heat the weld metals before they were ultrasonically welded. The materials were clamped between the Sonotrode and anvil and held there until the desired temperature was reached. Weld schedules were developed at several temperatures ranging from 100°F (37.7°C) to 500°F (260°C) and pull test data were plotted for each schedule data point. The graphs were then compared to the graphs of the original certification data taken at ambient temperatures. The material combinations evaluated include the following:

- Aluminum Alloy 1145-H19 (0.005 inch or 0.127 mm) to Aluminum Alloy 1145-H19 (0.005 inch or 0.127 mm),
- Aluminum Alloy 1145-H19 (0.005 inch or 0.127 mm) to annealed ETP Copper Alloy 110 (0.0027 inch or 0.0686 mm), and
- Hard T ETP Copper Alloy 110 (0.0053 inch or 0.1346 mm) to Hard T ETP Copper Alloy 110 (0.0053 inch or 0.1346 mm).

On all material combinations evaluated, heating the material to 150°F (65.5°C) resulted in a slight improvement over welds made at ambient temperatures. Both weld strength and repeatability were improved.

At temperatures above 150°F (65.5°C) weld strength and quality were reduced on both of the material combinations involving copper. While aluminum to aluminum welds exhibited slightly increased weld strength at these higher temperatures, the weld parameter range was significantly reduced and repeatability was decreased.

With the material combinations studied, the slight benefits derived by this process are offset by the disadvantages of special material handling and reduced system efficiency. Heated materials and the hot welding apparatus require special handling to protect the operator from burns. In addition, the use of the ceramic anvil "de-tunes" the weld system resonance and reduces the system efficiency. Therefore, this procedure is recommended only for marginally weldable material combinations that cannot be satisfactorily welded at ambient conditions.

Ultrasonic Ring Welding

Ultrasonic ring welders are used throughout industry for hermetic sealing transistor "cans," explosive containers, pyrotechnic packaging, and for many other configurations that cannot be welded by the more conventional arc or resistance processes. Ultrasonic ring welders have proven ideal for joining round parts such as eyelets and terminal studs to foil conductors and other component piece parts.

Ultrasonic ring welders employ torsional motion as opposed to the linear motion of an ultrasonic spot welder. This is accomplished by using a multiple transducer arrangement as shown in Figure 5. Since there is no linear motion, shear damage to small, delicate components can be avoided.

Ultrasonic ring welding has been evaluated for Bendix applications by the Sonobond Corporation of West Chester, PA, a manufacturer of ultrasonic welders. Small Aluminum Alloy 1100-H18 machined eyelets were welded to 0.002 inch (0.051 mm) Aluminum Alloy 1100-H19 foil laminated on both sides with Kapton insulation (Figure 6). The Kapton in the weld area was removed before the lamination process. Figure 7 is a cross-section view of the eyelet-to-foil weld, exhibiting a sound bond.

Terminations to Connector Hardware

Ultrasonic welding is being evaluated for direct terminations to connector hardware because of the increased usage of aluminum conductors in interconnection applications and the difficulty applying arc and resistance weld processes to these thin foils.

Previous welding processes used on aluminum foil conductors employed a series of transition joints to make electrical

Figure 5. Ring Welder Transducer Configuration

connections between cable conductors and component hardware. Ultrasonic welding has the potential to make direct terminations and reduce the required number of weld joints on a given system.

With the ultrasonic welding process, the material in contact with the anvil must be rigidly held. Connectors with removable contacts are ideal. Two simulated removable contact styles have been studied. Figure 8 shows a round style contact with the weld performed on the rear of the contact. This design requires a weld anvil drilled to rigidly hold the contact in a vertical position and is best suited for a 90 degree conductor breakout from the pins. Figure 9 shows a contact with a flat "tab" machined on it. The ultrasonic weld is made to the tab while the contact lays on a conventional design type anvil. This contact is well suited to a "straight out" conductor breakout but requires more space in the connector; contact fabrication costs are increased by this process. Figures 8 and 9 both show aluminum alloy 1100-H19 welded to beryllium copper alloy 172.

Figure 6. Aluminum Eyelet

Figure 7. Cross Section of Weld
Between Aluminum Eyelet
And Aluminum Conductor

Figure 8. Round Style Connector Contact

Figure 9. Tab Style Connector Contact

Since most connector contacts and shells are fabricated from beryllium copper, techniques had to be developed to overcome the material hardness dissimilarity between beryllium copper and aluminum which had prevented the welding of these materials. A Sonotrode weld tip was designed to maximize scrubbing at the weld interface by minimizing energy absorption in the Sonotrode itself. It was found also that the beryllium copper surface must be abraded to yield satisfactory weld results.

Ultrasonic welds can be made to connector shells limited by the constraint of adequate accessibility to both sides of the weld area. Figure 10 shows such an ultrasonic weld between an Aluminum Alloy 1100-H19 conductor and a gold plated Beryllium Copper Alloy 172 connector shell.

ACCOMPLISHMENTS

Pre-weld cleaning techniques were evaluated for their effectiveness in removing surface lubricants. Ultrasonic cleaning, spray cleaning, and wiping were found to be equally effective.

Surface finish effects were evaluated for their effects on ultrasonic welding of aluminum and copper alloys. Surface finish was found to have little effect on weld quality and material weldability.

The effects of nickel and gold plating on ultrasonic weld quality were investigated. Although two bonding mechanisms were observed, depending on the plating material, both types yielded satisfactory weld joints.

A method was developed for ultrasonically welding two circuit layers separated by Mylar insulation. The Mylar is melted and forced from the weld area by the clamping mechanism of the ultrasonic welder. A high quality weld can then be made between the two circuit layers.

Ultrasonic ring welding, a process using torsional rather than linear motion, was investigated for welding foil conductors to small eyelets. The process proved to be ideal for this application and provides a technique for welding several circular configurations.

The capability was established to make ultrasonic terminations of aluminum foil conductors directly to removable connector contacts and connector shells. Techniques were developed to overcome the material hardness mismatch between beryllium copper and aluminum which previously had hindered the ultrasonic welding of these materials.

Figure 10. Aluminum Conductor To
Beryllium Copper Weld

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