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**Westinghouse
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ATTACHMENT OF WELDABLE

STRAIN GAGES TO STRUCTURAL PARTS

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STRAIN GAGES TO STRUCTURAL PARTS

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D. C. Goldberg 1-20-65
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PREPARED BY:

L. G. Stemann
L. G. Stemann, Process Engineer

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APPROVED BY:

F. D. Seaman

F. D. Seaman, Adv. Engineer
Process Engineering

D. C. Goldberg

D. C. Goldberg, Manager
Structural Materials & Processes

DIST. 11

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SUMMARY

Attachment of Microdot Weldable Strain Gages requires that joints be produced between the welding flange of the gage and the structural part being evaluated. The process control required for reliably producing these welds has been explored and process specification PS 294543-9 was written to reflect the results of the study.

The welds, even though very small, represent a discontinuity which under some conditions may reduce fatigue resistance. This effect and means for eliminating it, such as material selection and plating prior to welding, have been evaluated.

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INTRODUCTION

Techniques for attachment of strain gages to structural parts within the NERVA reactor must produce gage to base metal bonds which withstand environmental conditions that include a broad spectrum of temperatures and high levels of irradiation. The organic cements that are normally used in other applications are not satisfactory for the intended usage. The Microdot Strain Gage is designed to facilitate attachment by resistance welding between the gage and the structural part as a means of providing the required environment-resistant bond.

The structural parts to which the weldable strain gages were to be attached were tie rods, lateral support springs and core bands. Each of these three parts is made from a different material that is in some manner degraded by the application of heat. The materials are Inconel 750 or 718, 301 stainless steel, and A 110-AT titanium respectively. This report details the processes and controls developed for the application of the weldable strain gage to each of the components in such a manner that the welding effect was minimized. The effect of the weld on the base metal was evaluated metallographically. A limited number of fatigue and tensile tests were run under another program and are summarized here in support of the metallographic findings.

Materials: As noted, the strain gages were to be welded to a variety of material types. Inconel 750, nickel base alloy, was in the fully aged condition at the time of attachment. The 301 stainless steel was in the full hard, cold worked condition. The A 110-AT titanium, while not in a heat treated or cold worked temper which could be easily modified by heat application, is subject to embrittlement through contamination and is not amenable to combination with a variety of other materials.

Gage Configuration: The typical external configuration of a Microdot Weldable Strain Gage with integral leads is shown in Figure 1. In the gage portion, a fine wire (Ni-Cr alloy)

sensing element is restricted and held inside a small diameter stainless steel tube by compacted magnesium oxide powder. A thin flange (.003-inch) is resistance welded to the body of the gage. This flange is provided to permit resistance welding of the gage to the structural part being instrumented. The welding flange is supplied either as 321 stainless steel or as a proprietary gold alloy.

Welding Equipment: Low power capacitor discharge welding equipment of the type shown in Figures 2 and 3 was applied in attaching the weldable gage to sample and production parts. A hand-held electrode was used with a ground lead either clamped to the part itself or to a flat copper back-up plate. This equipment permits the control of weld pressure and weld energy in terms of watt-seconds.

TIE ROD APPLICATION

General: Instrumentation of the tie rods was specified in order to determine stress and vibration levels. The weldable type of strain gage was selected for the application. Test samples were made using stainless steel foil to simulate the flange of the weldable gage so that proper welding technique for this particular application could be determined. Tensile and fatigue tests were run to establish effects of the welds on the mechanical properties of the base material.

Weldable gages with the configuration shown in Figure 1 did not fit the tie rod cylindrical contour satisfactorily and prevented the proper positioning of the electrode. Even though carefully selected energy settings, pressures and tip configuration were applied, weld spitting would occur because the gap between the flange and the base metal could not always be closed properly. Figures 4 and 5 show cross sections through typical defective welds on which spitting and other defects due to erratic positioning had occurred. Such conditions (Figures 4 and 5) necessitated

the development of a modified gage design, Figure 6, which permitted the welding flange of the gage to match the contour of the tie rod. Figure 7 is typical of the welds produced with properly selected welding conditions and with a contoured flange. The formation of an actual weld nugget may be seen along with a smooth indentation in the Inconel 750 base metal.

Many other process variables such as cleaning, electrode contour, lead length, etc., do have a considerable effect on the quality and consistency of the welding. A process specification designed to control all welding parameters was developed and used for all production applications. This specification (PS 294543-9 attached) provides for establishment of fixed weld schedules, control samples and metallographic acceptance where required.

Mechanical Testing: To evaluate the effect of the welding on the base metal properties, a series of specimens was produced by welding foils, which duplicated the strain gage welding flange in size and thickness, to sections of tie rods. Both tensile and fatigue properties were determined on these samples.

In direct tension no effect was observed and failure occurred at normal base metal strengths at a location well away from the area in which the foil was attached. In fatigue testing, however, considerable effect was noted on the performance of tie rod specimens. Flexural fatigue tests conducted at a mean stress of zero and 58,000 psi indicate that for a given life the allowable loading conditions would be considerably lower on specimens with gages attached by spot welding. S-N curves shown in Figures 8 and 9 illustrate this reduction.

Reducing Base Metal Effect: Variations of the attachment technique were attempted to reduce any effect that the weld zone might be exerting on the failure mechanism. A series of specimens was prepared by first applying a layer of braze alloy on the surface of the tie rod.

The irregular layer was then machined to give a controlled thickness of .003" to .005". Stainless steel foil shims simulating strain gages were spot welded over the braze area. The braze alloy employed was BAg-3 (1170°F-MP, 1270°F-FP). The spot welds were made at the minimum energy level that was observed to give adequate adherence. Tests indicated that this procedure gave little or no improvement in fatigue life.

Efforts to minimize and eliminate the metallurgical effects associated with weld nugget formation were further pursued by gold plating (.004 thick) the tie rod sections prior to attachment of the stainless steel foils that simulated gages. Welding was once again accomplished at the minimum energy level sufficient to give adequate adherence. Metallographic sections through joints produced in this manner (Figure 10) indicated that the heat effect of the weld on the base material had been reduced. The weld nugget (Figure 10) is no longer present in the Inconel 750 and precipitation or recrystallization is not apparent. Fatigue tests of these plated specimens showed a marginal improvement (Figure 9).

As an alternate to the stainless steel flange, the Microdot Weldable Strain Gage is supplied with a proprietary gold alloy foil as the welding flange material. Preliminary tests indicated that when this flange material was used with a properly established welding procedure, a braze type joint was formed in contrast to the fusion weld produced when the stainless steel flange was used. Thus a series of welds was made in which sample gold alloy foil was attached to Inconel 750 by the resistance welding technique. From the standpoint of joint strength and external appearance no problems were encountered. Microsections, however, revealed that while a braze type of bond had been formed, penetration of the base material by some constituent in the gold alloy had occurred (Figure 11). Because the effect of this undesirable condition could not be predicted with assurance, no tensile or fatigue tests were performed on sections produced by this type of process.

Failure Analysis: Study of the location of the fatigue failure indicates the following:

1. Failure occurred in all cases near the end of the shim material.
2. Failure did not occur through the welds but rather adjacent to them.

The observations noted above and illustrated in Figures 12 and 13 lead to the conclusion that the stiffening of the rod by the addition of the foil has at least a strong effect on the reduction of fatigue life. Referring again to Figure 10 (welds through a gold plate) the heat effect on the tie rod base material has been eliminated, yet failure still occurred in the same location at reduced fatigue life. However, the gold plate welds exhibited a slight gain in fatigue strength so the weld must influence the failure to some degree.

Thus in light of these findings, an attachment technique which would give continuous bonding and allow a smooth gradual transition from the buildup to base material should perform most satisfactorily. In support of this assumption limited tests on gages soldered in place (samples produced by Instrumentation and Control Department) exhibited the same strength as the unwelded specimens.

TITANIUM CORE BAND APPLICATION

Even though cyclic loading was not a problem on the titanium core band, the process of attaching the weldable strain gage had to be controlled to avoid or minimize formation of contaminated or embrittled areas. To develop the process controls, foils of stainless steel and the Microdot gold alloy were experimentally welded by the resistance technique to the A110-AT titanium alloy used in core bands. The stainless steel welds were typified by inter-metallics and cracking (Figure 14). The gold foil-to-titanium joints, however, were of a braze type with no evidence of base metal fusion (Figure 15). The heat affected zone of the base

material showed a very limited transformation at grain boundaries which was not considered detrimental to mechanical properties. No intergranular penetration was observed.

On the basis of the above observation, weldable strain gages for application to titanium are restricted by specification PS 294543-9 to the type with the gold alloy welding flange. In addition, metallographic inspection of sample welds for weld schedule qualification is required. An evaluation of a series of joints produced at increasing energy levels illustrates the importance of schedule control and metallographic inspection. Figures 16A, B, and C are sections through joints produced at 10, 15 and 25 watt-seconds of weld energy with all other factors being equal. These pictures illustrate the transformation of the weld from smooth, well-bonded configuration to one which shows evidence of expulsion and actual damage to the base material as weld heat increases. These detrimental effects cannot be readily observed in visual inspection.

In the qualification of production weld schedules for this application an additional feature of weld schedule control was highlighted. The first samples submitted were produced by several operators using the same equipment and procedures. A weld-energy setting had been set, after preliminary test, at 15 watt-seconds. Examination of the welds at 30X magnification showed irregularities between groups of samples. Excessive expulsion and possible damage to the base material was apparent upon external examination in some cases. This damage was confirmed by metallurgical examination. In other cases excellent joints were produced. These variations between good and bad samples were even found on duplicate tests submitted by the same operator.

Investigation revealed that the welding power supply being used was a 500 watt-second unit with a single control dial that covered the entire power range. The adjustment of this control at the low setting required for this particular application was not accurate enough to

provide consistent welding. A new welder rated at 40 watt-seconds was introduced and schedule qualification samples resubmitted. The new schedule developed called for a 12 watt-second setting. Samples were consistent and of high quality with cross section appearance similar to that shown in Figure 16A.

LATERAL SUPPORT SPRING APPLICATION

The attachment of the weldable strain gage to lateral support springs presented no problem. Compatibility of the 321 stainless steel welding flange to the 301 stainless steel spring was excellent. However, each weld between the flange and the spring resulted in localized softening of the cold worked material of the spring. This line of soft spots was potentially capable of reducing strength and creating points for initiation of failure under extreme loading conditions. Sample foils of the gold alloy were welded to the spring material. Evaluation of these joints indicated that under proper heat control little or no recrystallization (and thus softening) took place in the cold worked 301 stainless steel (see Figure 17). Thus for extreme loading or fatigue conditions the use of the gold alloy welding flange would allow attachment with minimum effect on base structure properties.

CONCLUSIONS

1. Metallographic inspection demonstrated that base material expulsion, creating notches and irregular cavities, occurred when improper welding techniques were employed. Further, it was demonstrated that incorrect selection of gage welding flange material may result in penetration into the base structure and formation of brittle intermetallics.
2. In one instance (Inconel 750 tie rods) when effects above were minimized by weld schedule control, the influence of the presence of a welded gage could still be detected in

fatigue testing. The endurance limit was lowered. However, for this particular component the service life was not effected.

3. There was no observable effect on tensile properties when proper welding techniques were employed.

4. The fracture location (near, but not in, the weld) suggests that the geometrical effect of the gage is a prime contributor. However, when a modification of the optimum welding technique, produced by interposing a layer of gold plate, was evaluated metallographically no evidence of degradation was observed and upon fatigue testing a distinct but small improvement was noted. This combination of events suggests that the nature of the weld also exerts an influence on fatigue performance.

5. When applying the weldable strain gage to structural parts it is extremely important that the welding flange be positioned uniformly to allow proper location of the welding electrode.

6. A prior gold plate of .005" on the structural part to which the weldable strain gage is being attached can minimize or eliminate the heat effect of the weld.

7. The standard Microdot gold alloy welding flange should not be used where weldable strain gages are being joined directly to nickel base alloys.

8. The standard Microdot gold alloy welding flange may be used, with proper weld schedule control, for joining weldable strain gages to A 110-AT titanium alloy.

9. The use of the Microdot gold alloy welding flange material, when joining gages to cold worked stainless steel such as the lateral support spring, reduces considerably the heat affected zone.

RECOMMENDATIONS

Based on the observations made during these process development programs, personnel responsible for specifying and carrying out the attachment of weldable strain gages should:

1. Establish the condition of the base material to determine if it is:

- (a) A material that can be contaminated such as titanium or a refractory metal

- (b) A material that has been conditioned by working or by heat treatment such that the application of heat will modify the material locally.

2. In the event that either 1(a) or 1(b) is found to be the case and the portion of the structure that is to be instrumented is subjected to any significant stress, then an evaluation of the effect of the gage-to-instrument weld should be made.

3. If a welded or brazed attachment method is used the process must be placed under proper control (such as that exemplified by Attachment 1).

FIGURE 1

Typical Weldable Strain Gage Configuration with Integral Lead

FIGURE 2
Capacitor Discharge Resistance (Spot) Welder
(without probe and hand piece)

FIGURE 3
Welding Handpiece and Ground Lead

FIGURE 4

200X

FIGURE 5

150X

Stainless Steel Foil Welded to Inconel 750 Tie Rod. Spitting and Erratic Weld Pattern Caused by Improper Electrode Positioning.

FIGURE 6

Modified Weldable Strain Gage Design to Allow
Correct Positioning on Tie Rod Cylindrical Contour. Extracted from Dwg. 978D211

200X

FIGURE 7

Stainless Steel Foil Welded to Inconel 750 Tie Rod. Joint
Produced with Correct Weld Schedule and Electrode Positioning.

Data supplied by WANL-Engineering Mechanics

FIGURE 8

Flexural Fatigue S-N Curves from Tie Rod Segments

FIGURE 9
Flexural Fatigue S-N Curves from Tie Rod Segments

STAINLESS STEEL FOIL

GOLD PLATE

INCONEL 750

200X

FIGURE 10

Inconel 750 Tie Rod Gold Plated Prior to Attachment of Stainless Steel Foil

100X

FIGURE 11

Gold Alloy Foil Welded to Inconel 750 Tie Rod
Typical Penetration of Gold Alloy into Base Material

FIGURE 12

9X

FIGURE 13

200X

Stainless Steel Foil Spot Welded to Inconel 750 Tie Rod Segment.
Location of Fatigue Failure with Respect to Welds.

FIGURE 14

100X

Stainless Steel Foil Welded to A110-AT Titanium. Intermetallic Formation and Cracking have Occurred.

FIGURE 15

100X

Gold Alloy Foil Welded to A110-AT Titanium. Braze Joint Formed with Limited Heat Affect in Base Metal.

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FIGURE 16

Welding Gold Alloy Foil to Titanium
Core Bands. Effects of Increasing
Weld Energy.

A - 10 Watt-Second
100X

B - 15 Watt-Second
100X

C - 25 Watt-Second
100X

100X

FIGURE 17

Gold Alloy Foil Welded to Full Hard 301 Stainless Steel. No Apparent Recrystallization of the Cold Worked Base Material has Occurred.

June 2, 1964

Resistance spot welding of weldable strain gages to structural parts.

1. MATERIALS

Form: Welding flange

Form: Structural parts

Thickness: 0.003 inch nominal

Thickness: _____

Type: AISI 321 stainless or
gold alloy (Microdot)

Type: Carbon, alloy or stainless
steels; Nickel and Cobalt -
base alloy; Aluminum and
Magnesium alloys.

NOTE: Type 321 stainless-steel welding flange shall not be used for attachment to aluminum and magnesium parts.

2. WELD PREPARATION

All oxides, dirt and other contaminants shall be removed from the base material prior to welding. *

2.1 Mechanical cleaning with an abrasive cloth or paper (400-grit final) followed by an acetone wipe shall be used on steels and nickel or cobalt alloys.

2.2 Chemical cleaning is recommended on aluminum and magnesium-base materials prior to welding. Apply a light coating of a deoxidizing agent (Walsco Electronics Manufacturing Co. #100-02, or Oakite 34M or equivalent) on the desired area. Lightly scrape the area using an X-acto knife or other sharp edged tool. After 2-3 minutes remove the agent by a thorough rinse with warm water.

3. PROCESS

3.1 The following equipment shall be required:

3.1.1 POWER SUPPLY: The power supply shall be a capacitor discharge type operated in a range of settings where reproducible weld energy adjustments may be made. Where wide variety in lead length and base-material type require the use of low and high energy levels a dual-range machine such as Weldmatic Model 1045 is recommended.

3.1.2 WELDING HEAD: The welding head shall have a handpiece with an adjustable electrode pressure from zero to 25 pounds maximum. A grounding probe or clamp shall be used on series type welds.

3.1.3 ELECTRODE: The electrode shall be a RWMA-Type II tapered to 0.040-inch face diameter.

3.2 The following general welding instructions shall apply:

3.2.1 Equipment check out prior to welding shall include a determination that all connections are clean and tight to assure that the resistance in the system does not fluctuate.

3.2.2 If the welding handpiece does not have a pressure-indicating gauge, an external pressure measuring device shall be used in the set up of weld conditions.

3.2.3 The electrode shall be polished with 400-grit abrasive cloth. If electrode sticking or weld spitting occurs the electrode shall be repolished.

4. PROCEDURE QUALIFICATION

A weld schedule shall be prepared and approved by WANL Quality Control prior to actual welding on a given application. The following factors shall be considered as essential parts of an acceptable weld schedule.

- Power supply and welding head
- Electrode type and configuration
- Cable size and length
- Grounding technique
- Weld energy
- Weld pressure
- Weld spacing
- Strain gage welding flange material and thickness
- Base-Material type, surface finish and cleaning procedures

4.1 The weld schedule shall be evaluated by peel testing of samples to confirm satisfactory weld strength. The sample flange material shall be peeled from the structure or test material. If a slug is pulled from the material, or if tearing occurs the weld has satisfactory strength. Samples shall be approved by WANL Quality Control. If required, metallographic sectioning shall be specified to evaluate welding effects on base material.

4.2 In developing a weld schedule a nominal pressure of three pounds shall be used and successive welds made at gradually increasing energy levels. If expulsion or electrode sticking occurs prior to obtaining a satisfactory weld, pressure shall be increased. If excessive indentation occurs prior to obtaining a satisfactory weld, pressure shall be decreased.

4.3 A minimum of ten consecutive welds having satisfactory peel strength and meeting the visual quality requirements of the section on weld quality shall be required to qualify a weld schedule.

4.4 Once the parameters for a single weld have been established, sample welds shall be produced at the spacing required by the drawing. The parallel path through the first weld may modify the weld condition and require a slight modification of the weld settings.

5. PROCESS CONTROL

Three sample welds shall be produced and tested prior to start-up after each 100 welds and at the completion of a welding operation. If the process control welds do not meet the requirements of this specification, all welds produced after the last acceptable test weld shall be rewelded or repaired as directed by WANL Quality Control.

6. INSTALLATION OF GAUGES

6.1 The gauge shall be held in proper alignment and welding started at the center of a desired line of welds and continued in the sequence shown below:

6.2 The electrode shall not be permitted to touch the gage tube as the parallel path may alter the weld energy.

6.3 Prior to attaching integral-lead gages, straps shall be placed over the lead tube in the location noted on the appropriate drawing and welded to the base material. If the straps are not the same material and thickness as the welding flange, an individual weld schedule shall be developed.

NOTE: This step is necessary to prevent stress on the gage and damage due to movement of the tube.

6.4 Where gages are attached to curved surfaces they shall be preformed to the contour of the base material prior to welding.

7. WELD QUALITY

7.1 Heavy discoloration, tip pick-up, no deformation, excess deformation and expulsion, indicate the possibility of a weak weld. A maximum of three welds of this appearance shall be permitted on each completed row of welds.

7.2 If more than three questionable welds occur in a row of welds, rewelding shall be done in the open areas closest to each of the questionable ones.

7.3 Requalification of the weld procedure and settings shall be required if rewelding is required on two successive rows of welds or on more than 25 percent of the rows produced.