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**Nd-YAG Laser Welding of the Fiber
Optic Connector to the Header Shell
on the ZSL Actuator**

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Abstract

An investigation was completed to determine the feasibility of laser welding a fiber optic connector at a right angle to the header shell of the 2SL actuator. The work was completed at the request of Los Alamos National Laboratory (LANL).

These studies showed a minimal temperature rise at the fiber-to-connector shell seal area and essentially no loss in light transmission after welding. Both metallographic sections and tensile pull-test failure values were obtained.

This study proves feasibility and with minimal change in parameters the penetration can be easily increased, which will yield higher tensile pull-test failure values.

Introduction

The purpose of this study was to investigate the feasibility of laser welding a fiber optic connector at a right angle to the header shell of the 2SL actuator. Before the study was initiated, filler washers were fabricated and used throughout the experiments to provide filler metal to enhance the strength of the weld. Both 0.010-inch x 0.010-inch (wall thickness) and 0.015-inch x 0.015-inch filler washers were used. Due to the limited number of actual parts provided by Los Alamos National Laboratory, several simulated parts were fabricated by EG&G Mound to support the study. After the Nd-YAG laser welding parameters were developed, thermocouple studies and diode laser light transmission studies (before and after welding) were completed.

There was a minimal temperature rise at the fiber-to-connector shell seal area and essentially no loss in light transmission after welding. Both metallographic sections and tensile pull-test failure values were obtained and will be given in this report. The tensile pull-test failure values were lower than expected. This was due to the limited penetration of the laser weld as will be seen in the metallographic sections. This study proves feasibility. With minimal change in parameters the penetration can be easily increased, which will yield higher tensile pull-test failure values.

The 2SL laser-ignited actuator is shown in Figure 1.

Figure 1 - Sketch of the 2SL Actuator.

Due to the lack of a welding lip on either of the pieceparts to provide filler material, a filler washer was designed and placed at the weld joint as shown in Figure 2.

The filler washers were fabricated from 304L stainless steel sheet material using the wire electric discharge machining (EDM) process.

In the case of the actual parts, the connector sleeve material was 303 stainless steel and the detonator shell material was 304L stainless steel. For the simulated parts, the connector sleeve was fabricated from 308L stainless steel and the detonator shell from 304L stainless steel.

Figure 2 - Sketch showing filler washers.

Procedure

A Raytheon Model 500SS Nd-YAG laser welding system was used. A Sensotec analog chart recorder was calibrated and used for the thermocouples. The thermocouple wire was chromel-alumel 0.005 inch in diameter and was placed near the fiber-to-shell seal area as shown in Figure 3. The tensile pull-test data was obtained with an Instron system and pull-tested at a rate of 0.05-inch/min. During welding, the parts were inclined 18 degrees (the connector was inclined 18 degrees off the vertical axis).

Results and Discussion

Eight experiments were completed. During these experiments, laser parameters were developed, thermocouple data were obtained, samples were made for metallographic cross-sectioning, and samples were made for tensile pull-testing. The laser parameters used for parts with the 0.010-inch x 0.010-inch washers and with the 0.015-inch x 0.015-inch washers are listed in Table 1. These data were obtained with simulated parts.

Figure 3 - Thermocouple locations.

TABLE 1 - Laser Welding Parameters				
POWER	FOCUS DIMENSION	PULSE RATE	TRAVEL SPEED	BEAM ALIGNMENT
35 watts (0.010-in. washer) 60 watts (0.015-in. washer)	3.90 inches	25 PPS	9.1 in./min	0.005 inch from washer edge

Figure 4 - Thermocouple trace for 0.010-in. washer. 30 cm/min chart speed. 10 mv/div full scale.

Figure 5 - Thermocouple trace for 0.015-in. washer. 30 cm/min chart speed. 10 mv/div.

Using the parameters shown in Table 1, thermocouple traces were obtained for each weld. The peak temperatures recorded using the 0.010-inch and 0.015-inch washers were 70°C and 111°C respectively. The thermocouple traces for the two washer sizes are given in Figures 4 and 5. These data were obtained using actual parts.

Next, simulated parts were fabricated, welded (using the parameters in Table 1), and metallographically evaluated.¹ Figure 6 shows the 0.015-inch washer weld; Figure 7 shows the 0.010-inch washer weld.

In general the welds look excellent except for the limited penetration into the base materials. The minimum weld throat on Figures 6 and 7 is measured at 0.0035 inch and 0.0045 inch, respectively.

Simulated parts were then used to obtain the tensile pull-test data. The parameters listed in Table 1 were used for these samples. The 0.010-inch washer weld failed at 82.4 pounds, and the 0.015-inch washer weld failed at 162.9 pounds.² If it is assumed that the fracture is a tensile-shear fracture (thus using a factor of 0.75), and use the minimum weld throat dimensions above, the laser weld ultimate tensile strength is predicted to be 87,000 psi for the 0.010-inch washer weld and 128,000 psi for the 0.015-inch weld. The variance in these two numbers is most likely due to the actual weld penetration in the pull-tested samples (which may be different from those measured in the photographs). Nonetheless, these numbers are not unreasonable based on the tremendous solidification rates involved with laser welds.

Figure 6 - Cross section of 0.015-in. washer weld (100x).

Figure 7 - Cross section of 0.010-in. washer weld (100x).

Solidification rates of this magnitude yield an extremely fine grain size and most likely the presence of a very fine 2nd phase (delta ferrite), both of which will tend to pin dislocations.³ In addition, solid solution hardening most likely occurs due to the entrapment of solute atoms (the rapid solidification prevents diffusion). This results in strain fields around the solute atoms. These strain fields will interact with the strain fields associated with dislocations, thus increasing the strength of the material during plastic deformation.

It is very important to note that the strength values quoted above are associated with relatively low strain rates. For high strain rates (such as those associated with the deflagration or detonation), metallic materials will exhibit some increase in strength with increasing strain rates.⁴

Using 304L stainless steel closure disc welds, the laser weld material strength has been reported to be on the order of 188,000 psi ultimate strength using strain rates that approach those associated with a detonation.⁵ Using the above ultimate tensile strengths and the area of the bottom of the connector, the pressure (generated inside the unit) to produce weld failure can now be determined.

The final experiment measured the diode laser light output through the

fiber connector before and after the welding operation. Before welding, the fiber was glued in place and the total energy transmitted was measured at 2.46 mJ. The connector was then welded in place and the total energy transmitted measured 2.32 mJ.⁶

This slight difference in the transmitted energy measured may be due to the weld. Most likely, the difference was due to disconnecting and reattaching of the connector on the opposite end of the fiber cable (which was necessary because of welding fixture constraints).

Conclusion

A study has been completed to characterize the laser welding of a fiber optic connector to the header shell of a 2SL actuator body. Laser welding parameters were developed, filler washers were fabricated, thermocouple data were obtained, metallographic cross sections of the welds were made, tensile pull-test failure values for the welds were obtained, and laser diode light transmission studies before and after welding were completed. Although additional parameter development is necessary (with minor changes) to yield increased penetration (to obtain higher tensile pull-test failure values), the study does prove the feasibility of the techniques.

Notes

1. Metallography work completed by P.M. Schleitweiler, EG&G Mound Analysis Log No. 8325.
2. Tensile testing completed by P.M. Schleitweiler, EG&G Mound Analysis Log No. 2016.
3. Conversation with Dr. C.M. Woods, February 8, 1993.
4. T. Z. Blazinski, "Effect of High Strain Rates on Material Properties," *Materials at High Strain Rates*, ed. J. Harding (London and New York: Elsevier Applied Science), p. 136.
5. C. W. Merten, EG&G memo to J.G. Harlan, Sandia National Laboratories, Albuquerque, January 10, 1989.
6. Experiment completed by T.M. Beckman, EG&G Mound, August 11, 1992.

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