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16. Abstract

The report describes a limited fatigue study to determine the influence of a repair using a melted solder to repair the galvanized coating after treatment of a mast arm weld toe by Ultrasonic Impact Treatment. The test results indicated that heating of the mast arm to melt the solder reduced the effectiveness of the treatment and also would be very difficult to perform in the field.

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Repair of Galvanizing After UIT Application

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Introduction

Ultrasonic Impact Treatment (UIT) to the weld toe of a galvanized mast arm removes the galvanizing in the treated area. UIT is applied to increase the fatigue performance of the mast arm by introducing compressive residual stresses at the treated weld toes and reshaping the intersection of the weld toe and the arm to reduce the local stress concentration. In order to prevent corrosion at the treated area, the weld toe must be recoated. There are various methods that can be employed to repair the treated area. The first method of repair is the application of zinc rich paint. Previous test results show that mast arms treated with a zinc rich paint after UIT application behave the same in fatigue as mast arms with UIT application without coating (Konenigs et al., 2003). The second method of repair is regalvanizing the treated arm in a hot-dip galvanizing bath. Previous tests show that hot-dip galvanizing after UIT application removes the benefit of UIT. A third method of repair uses a zinc-lead solder. The zinc-lead solder is applied to a heated surface at a working temperature of 600° F to 750° F, at which point the solder melts upon solidification repairs the galvanized coating. Metallizing could also be used but was not considered due the difficulty of using it in the field. This testing program was undertaken to determine the effect of solder repair on the fatigue life of UIT peened mast arm welds.

Previous Research

Mikheev et al. conducted tests of butt joints in high strength steel that were heated to 300°C (572^{o}F) after UIT application. Fatigue test results showed that when high strength steel samples were subjected to 300^{o}C temperatures after UIT application and before fatigue testing, there was no increase in fatigue life. The results of tests on treated and untreated specimens occupied a single scatter region characteristic of several fatigue tests of such welds (Mikheev et al., 1985). The extreme temperature may have relaxed the favorable, residual compressive stresses that UIT had induced in the surface layer of the specimens, resulting in no fatigue enhancement.

The effects of UIT when it is applied before and after hot-dip galvanization was examined in full size mast arm specimens in a previous research project. An attempt was made to compensate for the influence of hot-dip galvanization on the mast arm welds by using a modified treatment procedure. After a UIT technician performed the standard UIT application under loaded conditions using the 3mm diameter pins in the multi-pin tool along the toe of the socket weld, the same settings were used for an additional treatment to an area around the socket weld. The resulting condition of the socket weld after the heat affected area treatment is shown in Figure 1.

Figure 1: UIT Application to Both Weld Toes and the HAZ on TXuCLGP

After UIT the specimens were hot–dipped, galvanized and fatigue tested. Mast arm welds that had UIT application prior to hot-dip galvanizing performed very poorly in fatigue, indicating that the hot-dip galvanizing process negated any improvement induced by UIT (Konenigs et al., 2003). In contrast, when mast arms are hot-dip galvanized before UIT application, there is significant improvement in the fatigue life of the treated weld. Therefore, the improvements in fatigue performance from UIT are negated by hot-dip galvanizing after treatment.

Specimens

The two mast arms tested were untested mast arms from a previous project. The two mast arms tested after solder repair were labeled as TXuCLGP and TXuDLGP. Both mast arms had been previously shortened to 83 in. in length, with a 10 in. x 10 in. x 1 in. reaction plate welded to the smaller end. Mast arm TXuCLGP had an average outer diameter of 9.875 in., and mast arm TXuDLGP had an average outer diameter of 10.073 in. Both mast arms had a wall thickness of 0.1793 in. and were made of Gr. 50 steel. The end plates had dimensions of 12 in. x 18 in. x 1.25 in. The fillet weld connecting the mast arm to the base plate had been treated along the mast arm weld toe and heat affected zone (HAZ) with UIT by an Applied Ultrasonics technician while the specimens were subjected to a simulated dead load that produced a nominal stress of 16 ksi at the weld toe of the socketed connection.

Coating Repair Procedure

The repair was done with the specimens under load to simulate the stress conditions of a mast arm in the field. The specimens were initially loaded to a nominal stress of 28 ksi at the socket weld to determine the load displacement relationship for the specimens. The post treatment fatigue tests were performed using a minimum stress of 16 ksi and a maximum stress of 28 ksi to produce a stress range of 12 ksi. These were the identical test stresses used in the previous study. The repair was done with the specimens loaded to a nominal stress of 16 ksi. The temperatures of the specimens during the coating were recorded using a non-contact infrared thermometer. The emissivity setting on the thermometer, which is a function of the material and surface condition, was based upon calibration with thermal couple to measurements and was set to 0.98.

The solder used for the repair was Gal-Viz. Gal-Viz is a self-fluxing solder alloy for repairing damaged galvanized materials, produced by J.W. Harris, Inc. Gal-Viz is applied to metal at a working temperature of at least 600° F. Current TxDOT specifications allow the mast arm metal to reach temperatures between 600° F and 750° F during heat-applied solder galvanization repair. J.W. Harris, Inc. literature for Gal-Viz instructs the user to rub the Gal-Viz rod on the heated metal. When the Gal-Viz rod melts, the temperature of the metal is correct. This conveniently worked as a check for the non-contact thermometer, which fluctuated rapidly throughout the heating process.

The temperature was measured with a non-contact thermometer prior to heating at five locations on each mast arm. All five temperature reading locations were 1.5 in. from the mast arm weld toe. Two temperature reading locations were at either end of the UIT application line along the weld toe. The other three temperature reading locations were at the middle most area of UIT application. The temperature reading locations are shown in figure 2. The average temperatures for each specimen are shown in Table 1 with the maximum temperature for the central location also noted. The specimens were heated using an oxygen-acetylene torch with a rosebud style heating tip. Care was taken not to exceed the maximum temperature of 750^{o} F specified by TxDOT and to not jeopardize the UIT treatment. It was arbitrarily decided that mast arm TXuCLGP would be heated to the maximum allowed repair temperature of 750^{o} F, and mast arm TXuDLGP would be heated to the minimum allowed repair temperature, 600^{o} F, in an attempt to cover the extremes of possible field conditions. As noted in the table slightly higher maximum temperatures were recorded on the specimens.

Figure 2: Location of the Middle-Most Temperature Reading Locations (Circles Labeled D2, D3, and D4; The Endmost Temperature Reading Locations are Not Visible in this Picture)

Table 1: Recorded Temperatures

Specimen	Average Temperature Before Heating (^oF)	Maximum Temperature at Central Location During Coating (^oF)	Average Temperature After Coating (^oF)	Average Temperature 15 minutes After Coating (^oF)
C	75	770	240	150
D	70.1	650	185	153

The application of the solder to the mast arms was difficult. In order to limit the heat input and to simulate what would be the anticipated field procedure, the heat was applied only to the arm and not to the end plate. The large mass of the end plate relative to the thin mast arm absorbed the heat quickly when the heating torch was removed to apply the solder. Consequently, the solder did not flow well on the arm since the temperature of the surface of the arm dropped quickly below the solder's melting point when the heating torch was removed. The coated area had a pasty look, as shown in figure 3, not the smooth look of a properly applied solder. A higher initial temperature and heating of the end plate might have produced a better application of the solder; however, the higher temperature would be more likely to reduce the effect of UIT upon the fatigue performance.

Figure 3: Test Arm C After Application of Solder

The mast arms were allowed to cool for two hours to 81° F after the repair, and then the static test was run again. The deflection readings at maximum and minimum loads were recorded and used to set the displacement for the fatigue tests.

Fatigue Tests

The failure parameter for the mast arms were set as 5 percent change in the loads during the cyclic loading similar to the earlier tests. A maximum load limit is also set, in case of equipment malfunction, to protect the specimen from an overload.

The test reached the controller limits after 85,214 cycles of loading. The mast arms were visually inspected for cracks, and none were detected. At this point the controller had unknowingly been re-set, probably due to a brownout. When the test was restarted, the inadvertently re-set controller induced a deflection of 2.5 in., which caused a large fracture along the mast arm weld toe of TXuDLGP. A picture of this fracture after grinding to remove the galvanizing is shown in Figures 4 and 5. Figure 5 shows the angle created by the bending of the base plate of TXuDLGP during the loading. The fracture started from a fatigue crack at the weld toe of the specimen which had evidently caused the system to shut down.

Figure 4: Top View of Crack at Weld Toe of TXuDLGP

Figure 5: Side View of Mast Arm TXuDLGP After Cracking

Due to the extreme cracking and base plate bending, TXuDLGP was irreparable and could not be put back in the test setup to continue the fatigue test. Mast arm TXuBLGP had almost identical dimensions and fabrication conditions as TXuDLGP. TXuBLGP was put into the test setup in place of mast arm TXuDLGP on the north end of the test setup to continue the testing of TXuCLGP.

The controller shut down after reaching the control limits 101,865 cycles. A picture of mast arm TXuCLGP at this point is shown in Figure 6. Visual inspection revealed no fatigue cracks. However, the thick galvanized repair along the weld toe prevented good inspection. Since no fatigue cracks were visible in TXuCLGP, the controller was reset, and dynamic testing continued.

Figure 6: Mast Arm TXuCLGP After 101,865 Cycles

The controller reached a limit again after only 7,546 cycles at 109,411 cycles. A picture of mast arm TXuCLGP at this point is shown in Figure 7. Visual inspection revealed cracking in the thick solder repair. The solder was removed by scrapping with a screwdriver in the area of the cracking. No cracks were observed at the mast arm weld toe or surrounding metal. The controller was reset and dynamic testing continued.

Figure 7: Mast Arm TXuCLGP After 109,411 Cycles

The controller shut down a third and final failure for mast arm TXuCLGP 8,050 cycles later at 117,461 cycles. Visual inspection showed extensive cracking in the thick solder repair. Further removal of the solder with a screwdriver revealed visible cracking along TXuCLGP's mast arm weld toe. Removal of the entire thick repair with a screwdriver revealed the extent of fatigue cracking along the weld toe, as shown in Figure 8. The crack is highlighted in figure 9.

Figure 8: Mast Arm After 117,461 Cycles and After Removal of All the Repair Coating

Figure 9: Highlighted Fatigue Crack at Weld Toe

Discussion of Results

The inability to see the fatigue crack in specimen TXuDLGP after 85,214 cycles was probably due to masking of the crack by the solder used to repair the galvanizing. The crack on specimen TXuCLGP was not visible until it was very large and after the system had shut off 3 times from a change in specimen stiffness. It is interesting that TXuDLGP failed first, because this mast arm was heated to the minimum heat of about 600° F, while mast arm TXuCLGP was heated to 770° F.

The results of these two fatigue tests are compared with the identical specimens that had not been treated with UIT in Figure 10. The fatigue lives of the specimens repaired with galvanizing repair solder after UIT are slightly better than the specimens that had not been treated. However, their fatigue lives are much less than the specimens treated with UIT and not repaired with solder. Consequently, the heating of the specimens during the application of the galvanizing repair solder reduced the effectiveness of the UIT treatment. Note the thin end plates used in these specimens and the location of the longitudinal seam welds at the top of the arms produced a very low fatigue lives in all of the tests conditions relative to previous tests.

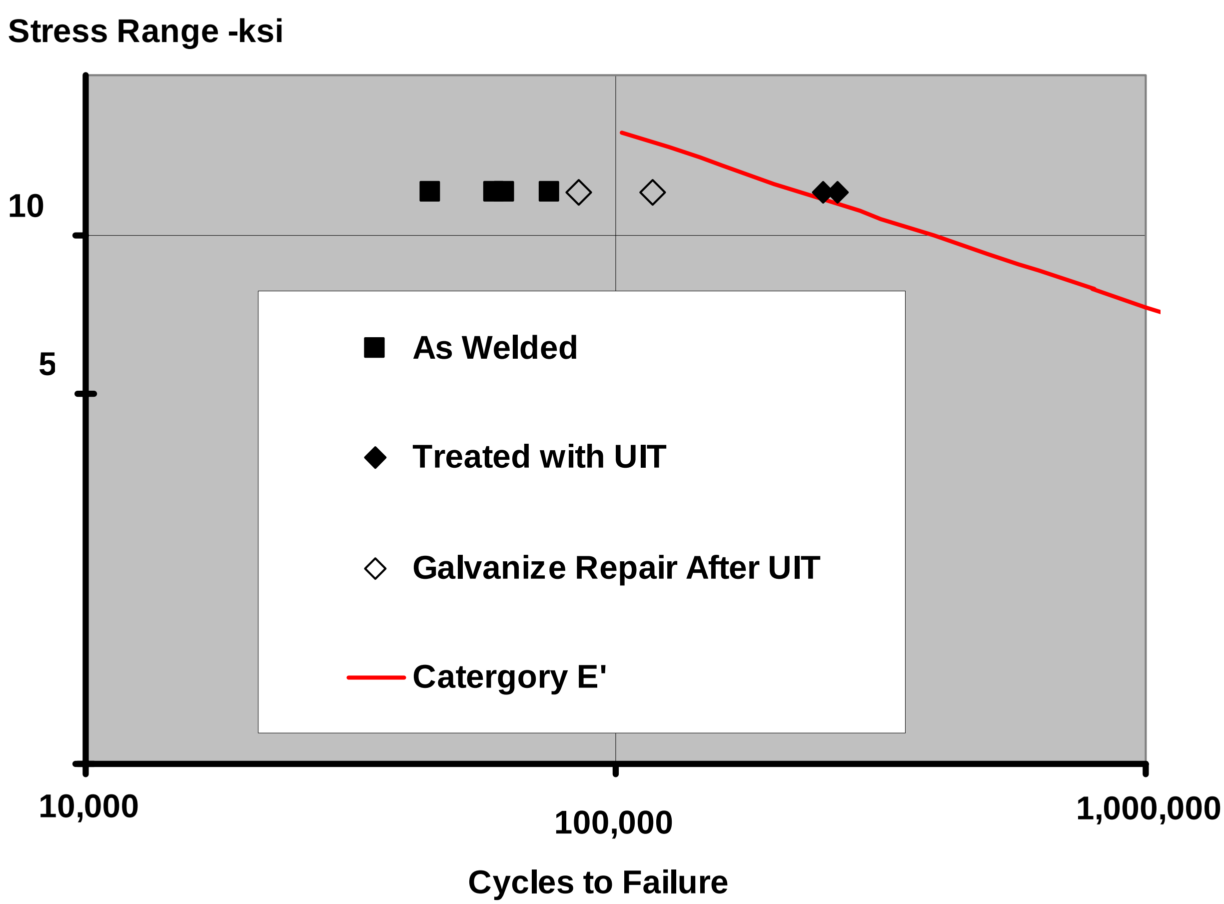

Figure 10: Fatigue Test Results

Recommendations

The use of galvanizing solder repair to connections treated with UIT is not recommended. The application of the solder repair reduced the improvement in fatigue life associated with the application of UIT. The solder was also difficult to apply due to the difference in thickness and mass of the mast arm and the attached end plate. The large end plate absorbed the heat applied to the mast arm making it difficult to melt the solder. The solder also masked the fatigue crack and made the cracks very difficult to see.

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