TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): North Carolina DOT

INSTRUCTIONS:
Lead Agency contacts should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Program Project # *TPF-5(493)*	**Transportation Pooled Fund Program - Report Period:** ☐ Quarter 1 (January 1 – March 31) X Quarter 2 (April 1 – June 30) ☐ Quarter 3 (July 1 – September 30) ☐ Quarter 4 (October 1 – December 31)

TPF Study Number and Title:
TPF-5(493) – Investigation of Dual Grade/Hybrid Steel Plate Girders Utilizing Stainless Steels

Lead Agency Contact: Jason Provines	**Lead Agency Phone Number:** (434) 293-1917	**Lead Agency E-Mail:** Jason.provines@vdot.virginia.gov
Lead Agency Project ID:	**Other Project ID (i.e., contract #):**	**Project Start Date:** 2/13/24
Original Project Start Date: 2/13/24	**Original Project End Date:** 11/13/26	**If Extension has been requested, updated project End Date:** N/A

Project schedule status:

X On schedule ☐ On revised schedule ☐ Ahead of schedule ☐ Behind schedule

Overall Project Statistics:

Total Project Budget	Total Funds Expended This Quarter	Percentage of Work Completed to Date
$400,000	$55,118.94	80%

Project Description:

Corrosion is a major concern for steel bridges, and if not properly designed for or mitigated, can lead to costly maintenance or service failures. One such option for making steel bridges more corrosion resistant is by using a dual grade girder, in which ASTM A709 Grade 50CR (50CR) plate is welded or bolted to conventional steel bridge girder components. In this case, the 50CR could be placed in a more corrosive environment, such as under a deck joint, and the conventional steel bridge material would be placed in other areas to allow for cost savings. However, there are still several unknowns related to welded and bolted dual grade connections.

This project will address those unknowns through experimental testing and analysis. Dual grade welds will be fabricated with different welding parameters, and PQR tests will be conducted to evaluate the welds for their structural performance. NDE research will be conducted to determine the suitability of eddy current to be used for weld inspection and to refine UT techniques to account for the high attenuation of austenitic weld metals and the different ultrasonic velocity and high anisotropic ratio of 50CR. Corrosion research will be conducted to assess the galvanic, stress, pitting, and crevice corrosion performance of dual grade connections. Results from that corrosion research will then be used to determine appropriate bolt types to be used in bolted dual grade connections. Additionally, torqued tension testing of stainless steel bolts will be conducted to determine tabulated values for installation pretension and installation criteria (such as rotation requirements for turn-of-nut installation).

After the experimental testing and analysis are complete, a final report will be developed. It will include recommendations for additions or revisions to be made in the AASHTO LRFD Bridge Design Specifications, AASHTO Bridge Construction Specifications, and AASHTO/AWS D1.5 that will allow welded and bolted dual grade connections to be designed, fabricated, and constructed successfully.

Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):

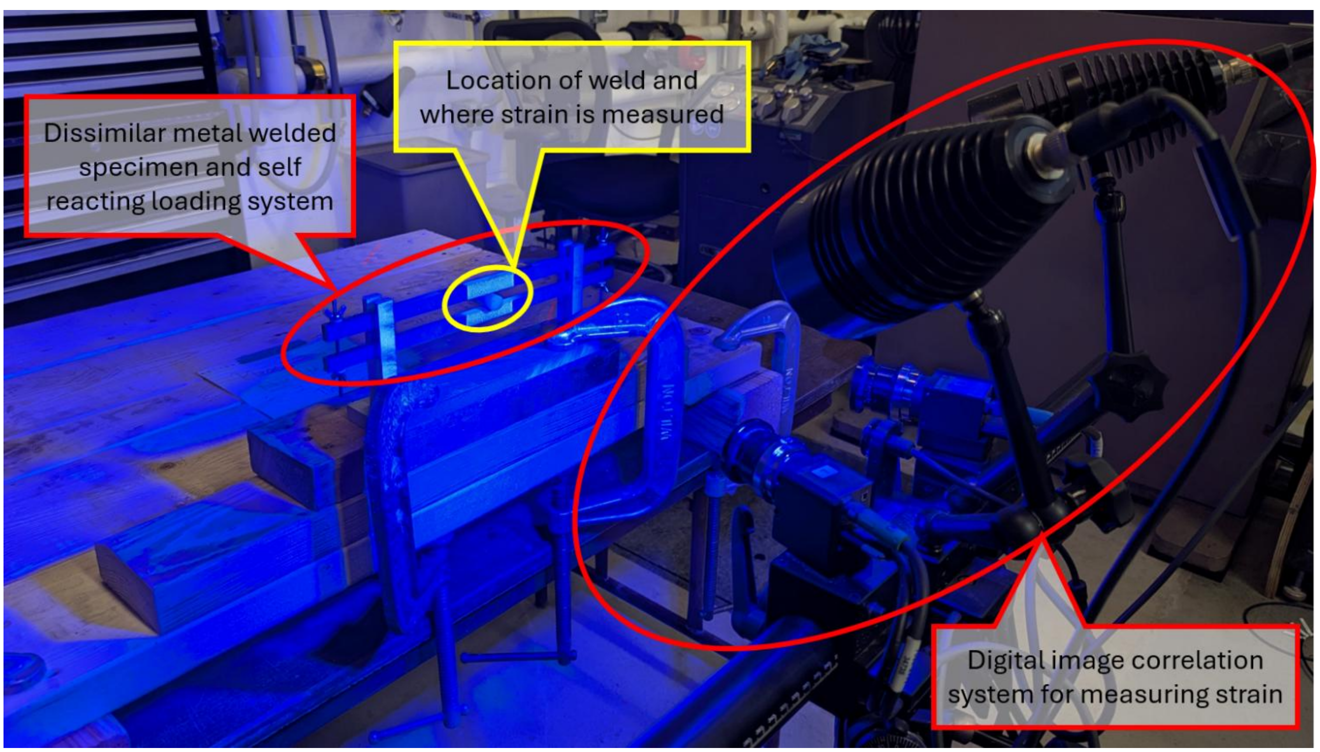
Task 1 – Literature Review

No work was done on this task. 100% completed.

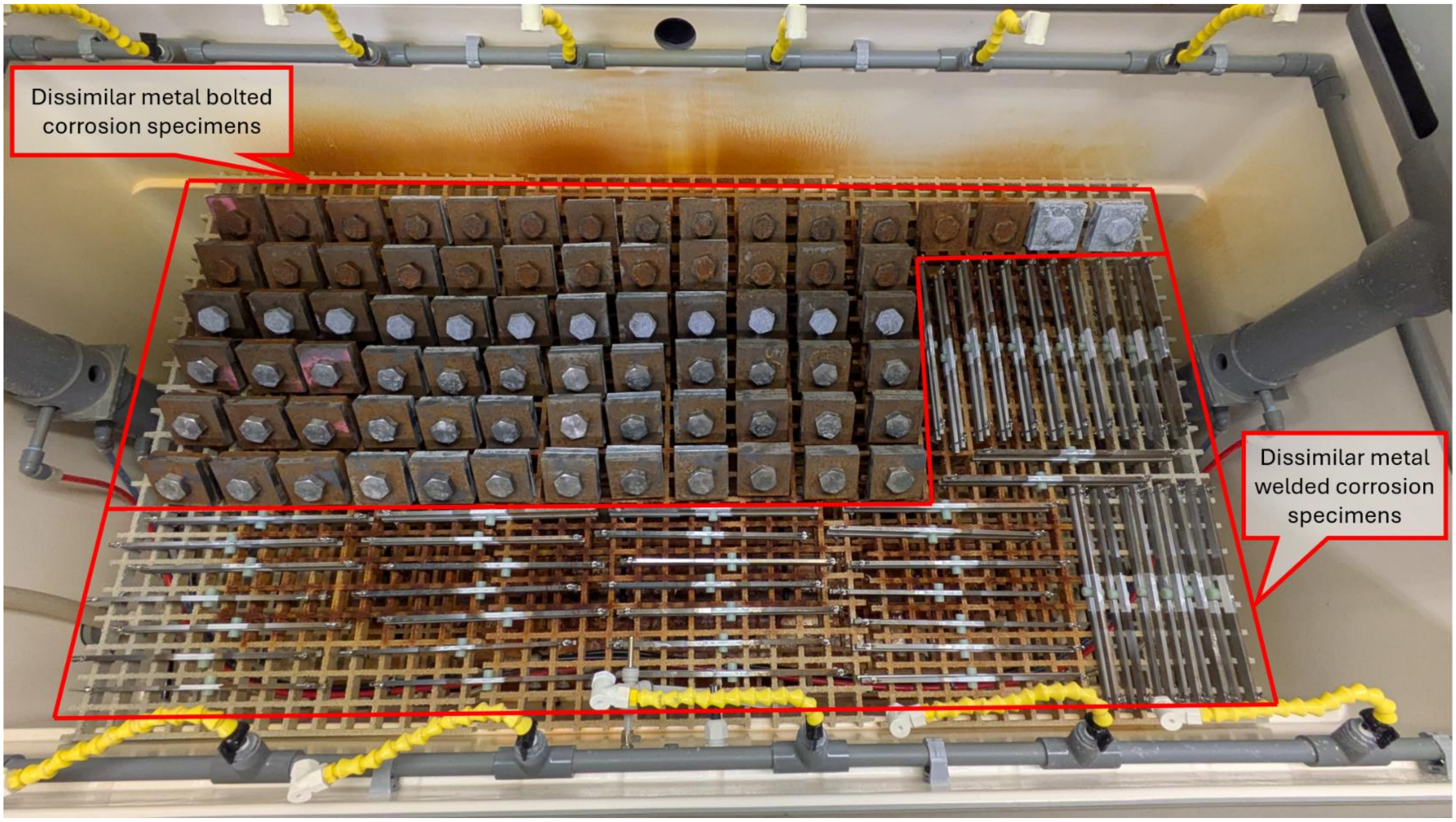
Task 2 – Connection Testing & Verifying Design/Fabrication Details

Task 2A – Welded Dual Grade Connections

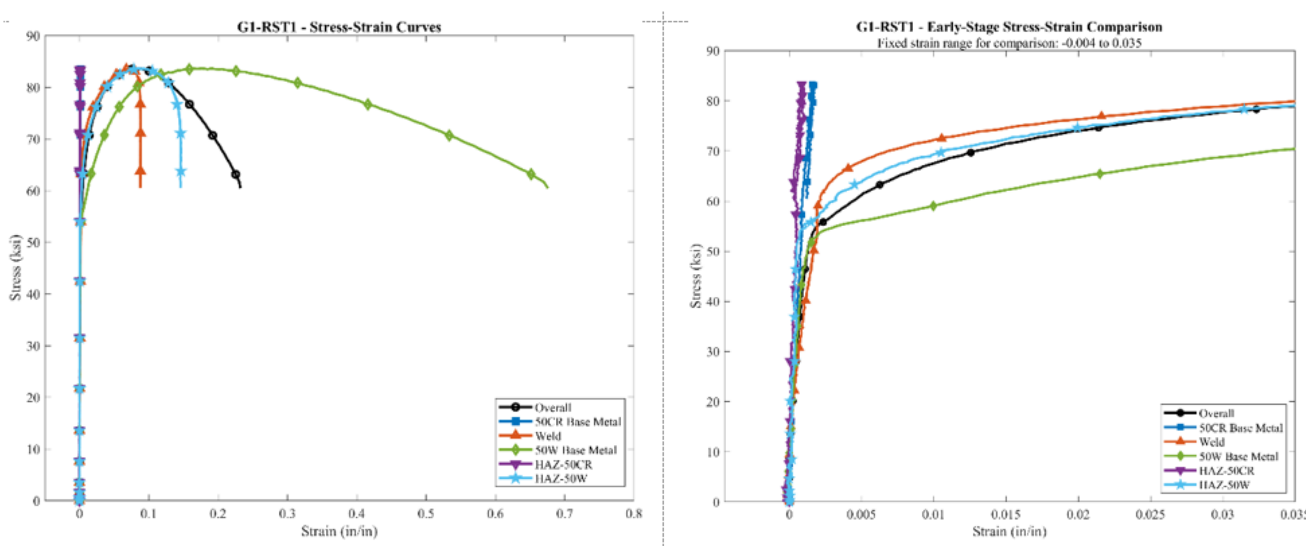
Stress corrosion cracking testing of the dissimilar metal welds is underway at VTRC. Three specimens of each different welding parameter were stressed to low, medium, and high stress levels, respectively. Stress levels ranged from approximately 5 ksi to 20 ksi. Stress levels in each specimen were measured using digital image correlation (DIC), as shown in the photo below.



Stress levels were maintained in each specimen, and then all specimens were placed in a corrosion chamber to undergo 80 cycles of corrosion testing following the SAE J2334 test method. Corrosion testing for the welded specimens began on 7/2/26. The photo below shows all the corrosion specimens inside the corrosion chamber.



Tensile testing of the dissimilar metal welded specimens was conducted at Utah State University using DIC to determine localized stress values in different regions of the specimen, including in both base metals, both heat affected zones, and the weld. The figure below shows results from specimens, G-1.

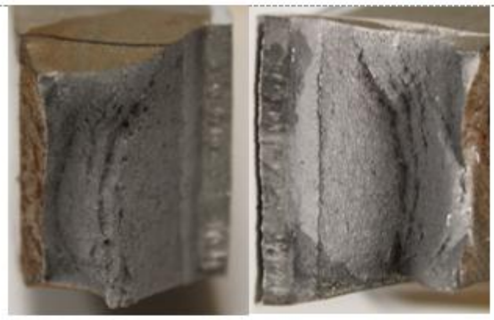


(a) (b)

Figure: (a) full stress-strain curves for G1-RST1; and (b) early-stage stress-strain curves for G1-RST1.

Yield stresses were typically calculated to be between 39-83 ksi. Ultimate stress values ranged from 80-91 ksi. For ultimate tensile stress, the 50W base metal requirement (70 ksi) was used as the reference criterion, and all specimens exceeded this value.

Most specimens fractured on the 50W side of the weld and experienced plastic deformation in the weld, 50W heat affected zone, and 50W base metal in all specimens. No fractures were observed in the 50CR base metal or 50CR heat affected zones. Specimens that fractured in the 50W base metal generally showed more ductility. Specimens that fractured in the weld region or 50W heat affected zone showed a must faster post-peak strength reduction. The figure below shows representative fracture surfaces from the tensile tests.



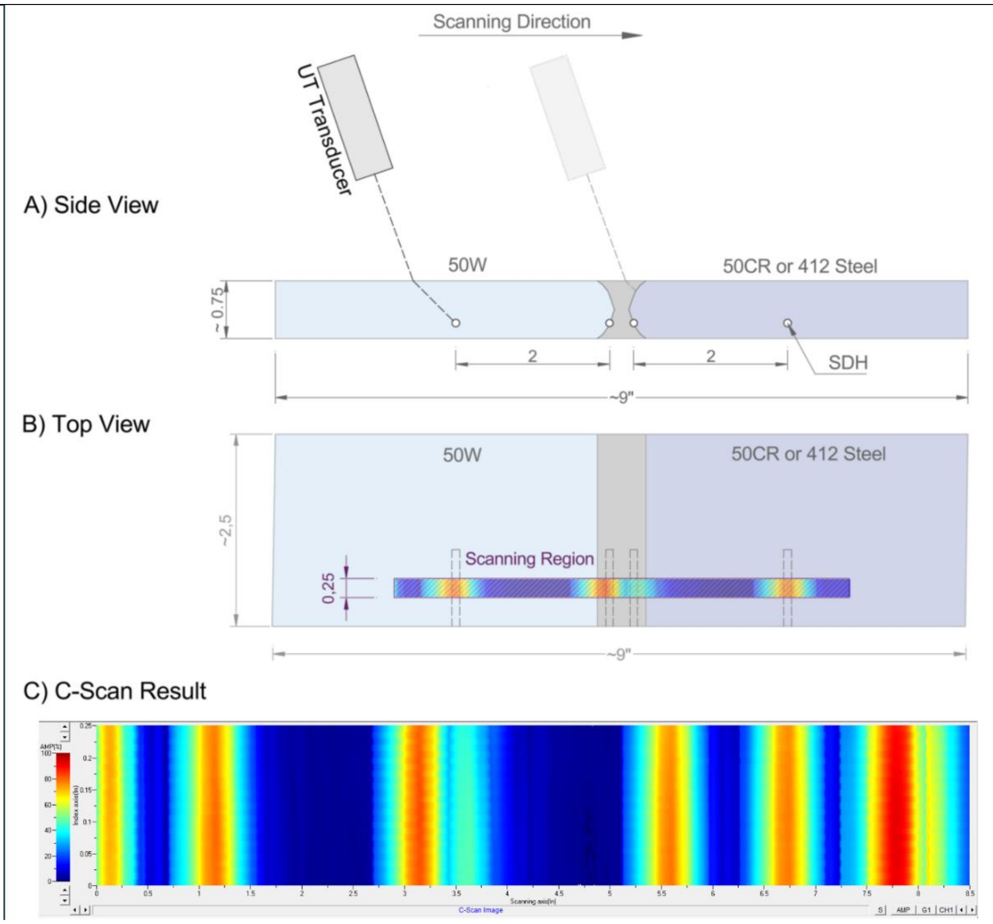
(a)

(b)

(c)

Figure:. Fracture surface morphology for representative specimens: (a) G1A-RST1, fractured in the weld region; (b) G1-RST1, fractured on the 50W side; and (c) G4-RST1, fractured near the HAZ-50W region.

Ultrasonic testing (UT) of the dissimilar metal weld specimens has continued at the University of Missouri with a focus on evaluating longitudinal-wave inspections for improved defect detection in the weld region. Testing was performed using angle-beam longitudinal waves at refracted angles of 45°, 60°, and 70° with transducer frequencies of 1, 2.25, and 5 MHz. Representative results obtained using a 2.25 MHz, 45° angle-beam longitudinal wave are shown in the figure below.



The C-scan displays reflections from the side-drilled holes (SDHs) located in the base metals and at the two fusion boundaries (weld metal–base metal interfaces), together with additional reflections from the specimen geometry. Compared with the shear-wave inspections reported previously, the longitudinal waves demonstrated improved transmission through the weld and successfully detected the far-side fusion-boundary SDH after propagation across the weld, although with reduced signal amplitude relative to the base-metal reference reflector due to scattering and structural heterogeneity within the weld. The detectability of the far-side fusion-boundary SDH was found to vary with refracted angle and transducer frequency. Testing of additional specimens is ongoing and will be followed by a quantitative comparison of signal attenuation across all wave configurations to identify the optimal inspection parameters.

Task is 80% completed.

Task 2B – Bolted Dual Grade Connections

Dissimilar metal bolting specimens considered in the project are shown in the following table. As indicated, the main types of plates include 50CR, 50W, and galvanized. The main bolting types include A325 Type 1, A325 Type 3, A325 Type 1 Galvanized, 2205 duplex stainless steel, 2507 duplex stainless steel, and 17-4 PH stainless steel bolts. In general, the bolted corrosion specimens consisted of a 50CR plate paired with a 50W, galvanized, or metalized plate, combined with each of the different bolting options. Specimens consisting of two 50CR plates were also included as control specimens. Additional control specimens included all-weathering steel specimens (two 50W plates with A325 Type 3 bolts) and all-galvanized specimens (two galvanized plates with A325 Type 1 Galvanized bolts). Three replicates of each specimen type were included, except for the all-weathering steel and all-galvanized specimens, of which there were two replicates.

Plate 1 Type	Plate 2 Type	Bolt Type & Accompanying Assembly	Quantity
50CR	50W	A325 Type 1	3
		A325 Type 3	3
		A325 Type 1 Galv	3
		2205 duplex stainless	3
		2507duplex stainless	3
		17-4 PH stainless	3
50CR	Galvanized	A325 Type 1	3
		A325 Type 3	3
		A325 Type 1 Galv	3
		2205 duplex stainless	3
		2507duplex stainless	3
		17-4 PH stainless	3
50CR	Metalized	A325 Type 1	3
		A325 Type 3	3
		A325 Type 1 Galv	3
		2205 duplex stainless	3
		2507duplex stainless	3
		17-4 PH stainless	3
50CR	50CR	A325 Type 1	3
		A325 Type 3	3
		A325 Type 1 Galv	3
		2205 duplex stainless	3
		2507duplex stainless	3
		17-4 PH stainless	3
50W	50W	A325 Type 3	2
Galvanized	Galvanized	A325 Type 1 Galv	2

Prior to assembling the specimens, multiple types of thickness measurements were obtained for each specimen. These thickness measurements included plate thickness, plate coating thickness, bolt head thickness, nut thickness, washer thickness, and galvanizing thickness on bolting assembling. Thickness measurements were used for the initial measurements in lieu of mass measurements so that localized thickness loss after testing could be better assessed. This was done because galvanized corrosion is expected to concentrate corrosion damage in specific locations, rather than general widespread corrosion across the entire specimen.

Bolting assemblies were fully pretensioned using the turn of nut installation method. Turn of nut rotation values for the A325 bolts were taken from the RCSC Specification. Nut rotation values for the 2205, 2507, and 17-4 PH stainless steel bolts were determined based on testing as outlined in the workplan for this project and according to the recently published AISC Design Guide 41: Structural Joints Using Stainless Steel Bolts. Specified pretension values were determined to be $0.7F_u$ for each of the three different types of stainless steel bolts. Nut rotation values required to reach these pretension values are shown in the table below. These nut rotation values were applied to the bolting assemblies for the corrosion specimens. Torque values were also recorded during bolt installation.

Bolt Type	Tensile Strength (ksi)	Specified Pretension for 7/8" Diam. Bolt (kips)	Bolt Length for 7/8" Diam.	Required Nut Rotation From Snug To Reach Specified Pretension
2205	95	31	Not more than 5d	1/3 turn
			More than 5d, but not more than 6.5d	1/2 turn
2507	116	38	Not more than 5d	1/3 turn
			More than 5d, but not more than 6.5d	1/2 turn
17-4 PH	135	44	Not more than 6.5d	1/3 turn

Once the bolting assemblies had been pretensioned for all the bolted corrosion specimens, the specimens were placed into a corrosion chamber to undergo 80 cycles of corrosion testing following the SAE J2334 test method. Corrosion testing for the bolted specimens began on 6/29/26.

Task is 80% completed.

Task 3 – Final Report & Guidelines

Minor preliminary drafting of the final report was done in this report period.

Task is 10% completed.

Virginia Transportation Research Council (VTRC)/University of Virginia (UVA) Dissimilar Metal Welding Research Project

The VTRC/UVA research project on dissimilar metal welds is complete. Findings from that study were shared in previous progress report. The final VTRC report was attached to the email with this progress report.

Anticipated work next quarter:

Task 1 – Literature Review

This task has been completed. No additional work planned.

Task 2 – Connection Testing & Verifying Design/Fabrication Details

Task 2A – Welded Dual Grade Connections

Corrosion testing of dissimilar metal welded connections will continue in the corrosion chamber at VTRC. 80 cycles of corrosion testing will be completed on 9/20/26. After testing is complete, the welded specimens will be visually inspected to determine if cracking is present in the weld metal or heat affected zones.

Utah State University plans to perform the galvanic corrosion testing of the dissimilar metal weld samples and continue to organize and review the tensile test results.

Missouri University will continue to work on the UT and evaluation of the dissimilar metal welds.

Task 2B – Bolted Dual Grade Connections

Corrosion testing of dissimilar metal bolted connections will continue in the corrosion chamber at VTRC. 80 cycles of corrosion testing will be completed on 9/20/26. After testing is complete, the specimens will be disassembled and the stainless steel bolts will be visually inspected for cracking. Difficulty in loosening the bolted connections will be documented during disassembly. In addition, plate thickness and coating thickness measurements will be measured and compared to initial measurements to determine the effects of galvanic corrosion.

Task 3 – Final Report & Guidelines

The research team will begin drafting the final report for this project.

VTRC/UVA Dissimilar Metal Welding Research Project

No additional work. This project has officially completed.

Significant Results:

Due to the early stages of this project, no significant results have been found yet.

VTRC/UVA Dissimilar Metal Welding Research Project

- Dissimilar metal welds made between 50CR/412 steel and 50W/A36 steel can meet the mechanical property requirements of the AASTHO/AWS D1.5 Bridge Welding Code. This requires using different welding parameters than those typically used for other steel bridge welds.

- Dissimilar metal welds made with 50CR/412 steel and A36/50W steel experience a significant reduction in corrosion resistance compared to non-dissimilar 50CR steel welds and the base metals in these welds. The heat affected zones of the weld and the base metals experience multiple forms of detrimental corrosion including uniform, pitting, galvanic, and intergranular corrosion. The corrosion resistance of the heat affected zones in these dissimilar metal welds is as follows, from greatest corrosion resistance to least: 50CR steel/309L weld metal >> 50W steel/309L weld metal > A36 steel/309L weld metal.
- Significant challenges remain with the nondestructive evaluation of dissimilar metal welds made with 50CR/412 steel and A36/50W steel. Radiographic testing using parameters typically used for other bridge welds has the potential to mask potential defects in these dissimilar metal welds. Due to the ultrasonic anisotropy of dissimilar metal welds, defects in the welds can be missed or mislocated using traditional ultrasonic testing calibration processes. Further, ultrasonic wave refraction can lead to missing or mislocating defects in these welds when inspecting them using traditional ultrasonic testing or phased array ultrasonic testing.
- 412 steel is a potential alternative to 50CR steel. 412 steel has a similar chemistry to 50CR steel, which gives it a similar corrosion resistance, has similar mechanical properties to 50CR steel, and is regularly produced by a domestic steel supplier. However, it does not meet the current heat treatment requirements for Grade 50CR steel as specified in ASTM A709.

Circumstance affecting project or budget. (Please describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).

None.

Potential Implementation:

The primary research product will be the final report as developed in Task 3. Recommended changes to the AASHTO LRFD BDS/BCS and AWS D1.5 will be included in appendices within the report and will be based on the combined results from this research and the VTRC/UVA research dual grade welding research. Recommended changes will be written in a similar format to the specifications for which they are intended (i.e., recommendations for AASHTO specifications will follow a two-column specification/commentary format, and recommendations for D1.5 will follow a two-chapter specification/commentary format.). Using a similar format to existing specifications will allow these revisions to be more easily balloted and adopted.

The research team will present at conferences, meetings, and the AASHTO/NSBA Collaboration as well as develop journal publications to disseminate research findings to the steel bridge community. The research team will also present recommendations to the AASHTO Steel and Metals committee for review/adoption into the AASHTO LRFD BDS/BCS and to the Joint AASHTO/AWS Bridge Welding Subcommittee for review/adoption into AWS D1.5.