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October 2, 2023

Mark Smitherman
ATI Advanced Technology International

2019-375-008 (EWI Project No. 59089GTH), "NSRP Panel Project – High Productivity Reduced Emissions Arc Gouging Process"

Dear Mark:

Enclosed is EWI's final report for the above referenced project. Please feel free to contact me at 614.688.5273 or jrausch@ewi.org if you have any questions or comments regarding this project.

Sincerely,

Jason Rausch
Applications Engineer

Enclosure

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NSRP Panel Project – High Productivity Reduced Emissions Arc Gouging Process

October 2, 2023

NSRP 2019-375-008
EWI Project No. 59089GTH

Submitted to:
ATI Advanced Technology International

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Final Report

2019-375-008
EWI Project No. 59089GTH

on

NSRP Panel Project – High Productivity Reduced Emissions Arc Gouging Process

to

ATI Advanced Technology International
Mark Smitherman

September 18, 2023

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Executive Summary

An alternative to Carbon Arc Gouging (CAG), WeldVac is a new advancement in the removal of metals. WeldVac can have an impact on ambient environmental quality by the reduction and/or elimination of spatter, slag, fume opacity, carbon dust, and noise. In addition, cost reductions may be achieved by the reduced amount of area protection that now must be placed on everything within 100 or more feet of CAG operations. Further, other trades and jobs may be performed nearby due to the quieter and cleaner nature of WeldVac. At present, shipyards use CAG for steel weld removal and back-gouging operations, requiring extensive protection of large areas and rendering the local work area uninhabitable for other workers. CAG generates large quantities of hot slag that may start fires. CAG leaves debris that takes time to clean up. Even after cleanup, CAG operations typically leave residual carbon dust that could foul electronics and other equipment. WeldVac uses a capture device through vacuum suction that can trap the particulates and fumes.

This report relays the evaluation of the WeldVac system, the modifications made to enhance the system's performance, and the potential applications where WeldVac could have a positive impact on shipyard work that were identified during the demonstration at Vigor. Some of the design modification recommendations include:

1. The current WeldVac system is a successful reduction-to-practice alpha prototype model that shows the process can produce geometrically uniform gouges that are free or nearly free of surface oxides under carefully controlled conditions. With that said, the system needs to undergo further product development for refinement to get it to production-ready, commercially available status.
2. Under carefully controlled conditions in a laboratory environment, the WeldVac system can make good gouges on steel, stainless steel, Cu-Ni, and aluminum base materials.
3. The WeldVac system will likely show itself to be superior to CAG in reduced noise and process fume generation once a torch is developed that can function without clogging or degrading due to melting.

Personnel at the Vigor shipyard recommended three applications that WeldVac could be of great benefit to the shipyard after undergoing further product development. This report details these applications in further detail:

- Removal of fairwaters and rope guards that encase the space between the end of shaft struts and the propellers.
- Removal of weld reinforcement on aluminum butt joint welds joining ship deck plates.
- Removal of fillet welds in steel t-joint and deeper gouging capabilities when said operations need to be done in an environment that has high-value equipment (i.e., computer systems).

Abbreviated Terms

CAG	carbon arc gouging
CTWD	contact tip-to-work distance
Cu-Ni	copper-nickel
GTAW	gas tungsten arc welding
ID	inner diameter
OSHA	Occupational Safety and Health Administration
PTR	principal technical representative

1.0 Introduction

An alternative to Carbon Arc Gouging (CAG), WeldVac is a new advancement in the removal of metals. WeldVac can have an impact on ambient environmental quality by the reduction and/or elimination of spatter, slag, fume opacity, carbon dust, and noise. In addition, cost reductions may be achieved by the reduced amount of area protection that now must be placed on everything within 100 or more feet of CAG operations. Further, other trades and jobs may be performed nearby due to the quieter and cleaner nature of WeldVac.

At present, shipyards use CAG for steel weld removal and back-gouging operations, requiring extensive protection of large areas and rendering the local work area uninhabitable for other workers. CAG generates large quantities of hot slag that may start fires. CAG leaves debris that takes time to clean up. Even after cleanup, CAG operations typically leave residual carbon dust that could foul electronics and other equipment. WeldVac uses a capture device through vacuum suction that can trap the particulates and fumes.

At the outset of this project, WeldVac was to be evaluated for overall process performance, subjected to environmental testing, compared to the CAG process, and demonstrated at Vigor’s Weld School. While environmental testing and comparison to the CAG process was not able to be accomplished, the assessment of the WeldVac system did take place, and a successful demonstration of the system at Vigor occurred. This report relays the evaluation of the WeldVac system, the modifications made to enhance the system’s performance, and the potential applications where WeldVac could have a positive impact on shipyard work that were identified during the demonstration at Vigor.

2.0 Objectives

The objective of the proposed project was to evaluate the WeldVac GTAW gouging system and to compare WeldVac metal removal methods with that of the CAG process on shipbuilding steel. A goal was to assess potential reduction in cost and the associated time of using WeldVac in lieu of CAG for specific metal removal tasks, including new construction, overhaul, maintenance, and repair operations.

A major part of the project was intended to test WeldVac with U.S. Navy and/or ABS new construction, maintenance, and/or repair scenarios to establish the actual environmental and productivity attributes of the process. This would verify that WeldVac methods could provide satisfactory removal rates for welds and other materials in U.S. Navy and ABS activities while consistently meeting OSHA and other requirements by reducing noise, auxiliary damage, and fume opacity, while improving the entire spectrum of operations in the areas adjacent to where CAG is now performed The main value proposition for WeldVac is the potential reduction in labor and material for protection of adjacent equipment, the reduced amount of clean-up required, and the fact that other trades can work in relatively close proximity to the actual metal removal operations.

During execution of the original scope of work, it was determined that the WeldVac system required more modifications than originally expected to improve performance for the target shipyard application. Torch components for the system had to be reverse engineered and machined for multiple iterations to support the extensive testing required to confirm the system is operational for demonstration.

After discussions with the principal technical representative (PTR) and ATI’s project manager, the recommended path forward was to spend the funding that was planned for environmental testing and comparison to the CAG process on continuing to modify the WeldVac system to ensure a successful project demonstration of the system at Vigor. By demonstrating this system, participants would observe quieter conditions and less debris; however, this would not be proven with environmental testing but will be the first step towards understanding the benefits of this system.

3.0 Experimental Procedure

With the adjustment in scope as described in the Objectives section, the experimental procedures were revised to remove environmental testing and put an emphasis on the modification of the WeldVac torch to improve performance for the target application as described in Section 2. Details of each task are described below.

3.1 Task 1 – Project Initiation and Kick-off Meeting

The project was initiated, subcontracts issued to funded participants, and a kickoff meeting was held with all project partners: BSI Environmental Health and Safety, CSK Mechanical, and Vigor Shipyard. (Note: Initially Bollinger Shipyard was a project participant, but they withdrew from the project at the very beginning since they are no longer a part of NSRP.) Additionally, the PTR from industry supporting this effort, as assigned by ATI, was Maurissa D’Angelo from D'Angelo Technologies, LLC. A few months into the project, the PTR was changed to Victoria Dlugokecki, a Naval Architect/Marine Engineer.

During the project kickoff meeting, the following items were planned for discussion:

- Determine performance testing joint designs, positions, and requirements.

- Identify procedural boundaries (i.e., weld sizes, methods, etc.).
- Determine the parameters to be tested (noise, breathing zone, fume generation, productivity, etc.).
- Determine desired metal removal rates (e.g., lb/hr or linear fpm of fillet weld).

3.2 Task 2 – Identification of WeldVac Parameter Sets

A WeldVac system was delivered and set up at EWI to conduct project objectives. A carbon arc gouging system was also assembled at EWI to support the comparative objectives. Charlie Klangos, inventor of WeldVac, provided system setup and training to an EWI engineer and technicians. The system was not supplied with ample consumable torch parts for project execution, nor were drawings of the parts supplied. These torch parts were reversed engineered and fabricated so that the project objectives could be initiated. Parameter development was conducted to evaluate the WeldVac systems. Throughout the parameter development process system component design modifications were carried out to increase the consistency, repeatability, and performance of the system.

3.3 Task 3 – Demonstration and Implementation

The WeldVac system was shipped to Vigor and set up in the shipyard’s Weld School. Gouges were demonstrated to shipyard personnel using the parameters developed for DH36 steel in Task 2. Gouge trials were also conducted on aluminum and copper-nickel (Cu-Ni) alloys. EWI collected feedback from shipyard personnel who attended the demonstrations. The feedback is included in the Future Work section of this report.

3.4 Task 4 – Technology Transfer and Reporting

The purpose of this task was to report on the ongoing progress and outcome of the project. This reporting included a briefing to the NSRP Environmental, Health, and Safety Panel; quarterly reporting to ATI; and a final written Microsoft Word report.

4.0 Results

4.1 Task 1 – Project Initiation and Kick-off Meeting

Per the project proposal, during the project kick-off meeting, the following items were slated for discussion and subsequent planning:

- Determine performance testing joint designs, positions, and requirements.
- Identify procedural boundaries (i.e., weld sizes, methods, etc.).
- Determine the parameters to be tested (noise, breathing zone, fume generation, productivity, etc.).

- Determine desired metal removal rates (e.g., lb/hr or linear fpm of fillet weld).

At the time of project initiation and kick-off meeting, the WeldVac system had yet to be delivered to EWI, and little information regarding the WeldVac system itself or its ability to perform gouges on various joint designs and position was known to EWI. Consequently, the decision was made to wait until the WeldVac system had been delivered to EWI and EWI personnel had been trained. The pause would also allow the system to undergo basic evaluation so that EWI personnel could understand WeldVac's current capabilities before mapping out specific joints to test, procedural boundary conditions, and testing matrixes.

4.2 Task 2 – Identification of WeldVac Parameter Sets

Mr. Charlie Klangos delivered the system to EWI in March 2022 and worked with an EWI engineer and technicians for three days on system setup and basic operation training. The following are topics that were covered and discussed during this time:

- Overall system components and setup
- Function of system variables and their influence on the process
- Critical setup features at the torch tip to promote ideal melting and material removal
- Troubleshooting techniques for common problems
- General process window of parameters (amperage, tungsten placement, suction, etc.) that have worked well on previous steel and stainless steel applications
- Areas of possible design improvements regarding the current prototype

The WeldVac system was an alpha-prototype that was a basic reduction to practice model. The travel motion was provided by a welding tractor that Mr. Klangos brought down temporarily just for the system hand-off and training session. While the system did function during Mr. Klangos's initial visit, he communicated that it was not operating at the same level that he had known it to up to that point. Mr. Klangos noted that it was making smaller gouges, and buildup of slag was clogging the torch body more so than he had experienced before.

EWI attached the WeldVac torch to a linear side beam for further project development. The WeldVac system consists of the following main components, Figure 1:

- GTAW Torch
    - The welding torch arc liquifies the base material to create a molten weld pool that can then be removed by the vacuum.
- WeldVac Nozzle assembly

    - The nozzle assembly is comprised of aluminum tubular components (torch body, nozzle adapter, and tip with integrated sip port) that direct the suction at the molten weld pool, Figure 2.
- Extraction Hose (from WeldVac nozzle to containment box)
    - This hose conducts air flow and extracts metal from the WeldVac torch to the containment box.
- Containment Box
    - The purpose of the containment box is to provide a path for the extracted flume and slag so that its momentum will cause it to be entrained in the fluid in the box.
    - The containment box can be sufficiently filled with water so that extracted melt will be cooled and remain in the containment box not traveling further to the vacuum exhaust.
    - The valve on the containment box operates to control the amount of airflow volume and velocity at the WeldVac Torch where the gouge is taking place. If the valve is fully closed, all airflow is being directed solely through the WeldVac torch. If the valve is partially or fully open, a varying percentage of the airflow is pulled into the containment box through this secondary opening, which consequently reduces the airflow through the WeldVac torch.
- Exhaust Hose (from the containment box to vacuum source)
    - This hose conducts airflow from the containment box to the vacuum source.
- Vacuum Source
    - The vacuum source used for the WeldVac system was a 6.0 HP shopvac.


Figure 1. WeldVac System Component Overview

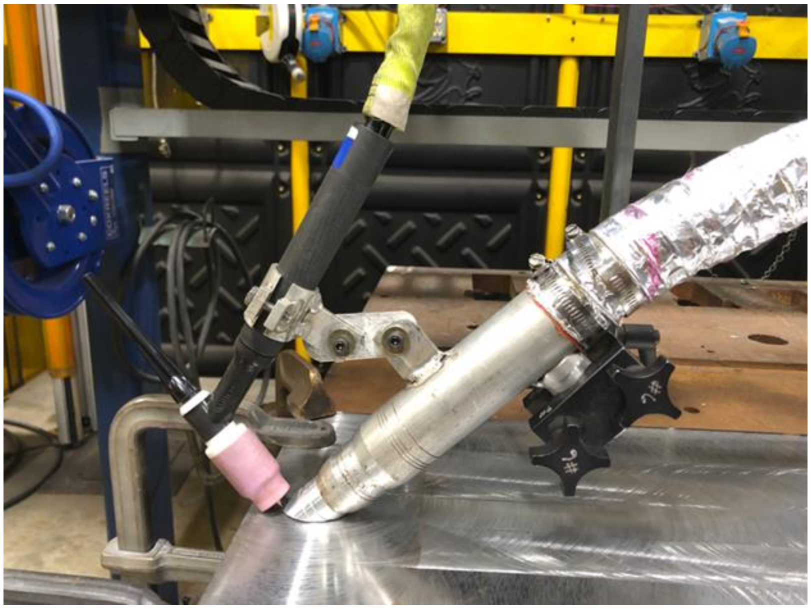
Figure 2. WeldVac Torch Component Overview

WeldVac had mostly been operated and demonstrated by Mr. Klangos to make linear gouges on flat plates. Mr. Klangos did bring along a prototype hand-held torch that he had used on both flat plate and t-joint configurations to remove fillet welds, but he was not able to get the hand-held torch functional during his time at EWI, Figure 3. Based on the lack of functionality of the hand-held torch, EWI identified that the gouging trials should be conducted on flat plate with motion provided by either a mechanized welding tractor or a side beam.

Figure 3. WeldVac Hand-Held Torch Version

EWI initially ran the WeldVac system on a linear side beam, as seen in Figure 1, but the system was eventually attached to a Gulco welding tractor so that it could be more easily transported to the demonstration at Vigor shipyard, Figure 4.

Figure 4. WeldVac Mounted on a Gulco Welding Tractor

EWI was able to use the WeldVac system to make gouges, but challenges were encountered that inhibited project progress. The main issues were the melting of nozzle components, the clogging of the nozzle, and the repeatability/consistency of the process. In Figure 5, Trial 612-3 successfully melted the base material but did not extract to create a gouge, whereas Trial 612-9 successfully melted the base material and extracted it to make a gouge.

Figure 5. Initial Gouge Attempts on Steel Plate

The sip port on the tip of the three-piece torch would partially melt during gouging, consequently changing the geometry of the sip port, Figure 6 and Figure 7. The geometry had a large influence on the resulting gouge. The extent of sip port melting would vary from gouge to gouge, making for a wide variety of gouge cross-sectional geometries. The melting of the sip port would sometimes contribute to and exacerbate the clogging at the sip port which would result in the immediate loss of a gouge.

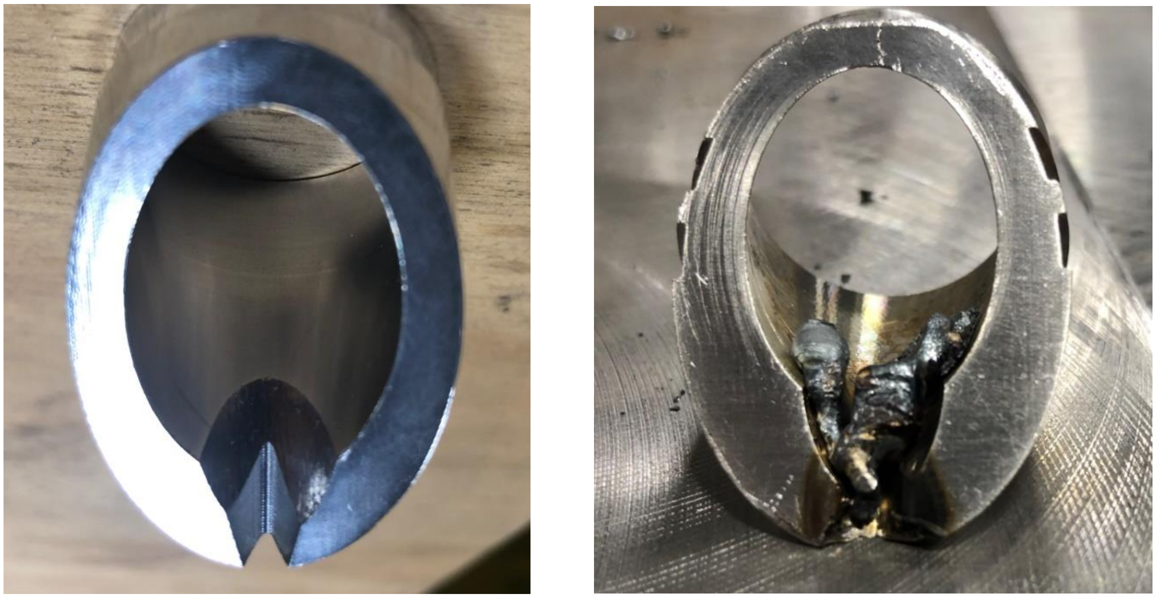

Figure 6. New Tip with Integrated Sip Port (left) **and Partially Melted and Clogged Tip after Making a Short Gouge** (right)

Figure 7. Melted Tip with Significant Geometrical Changes to the Sip Port.

When excessive clogging occurred in the tip or nozzle adapter region, the tip would heat up and undergo significant failure with melting both at the sip port and interface with the nozzle adapter, Figure 8.

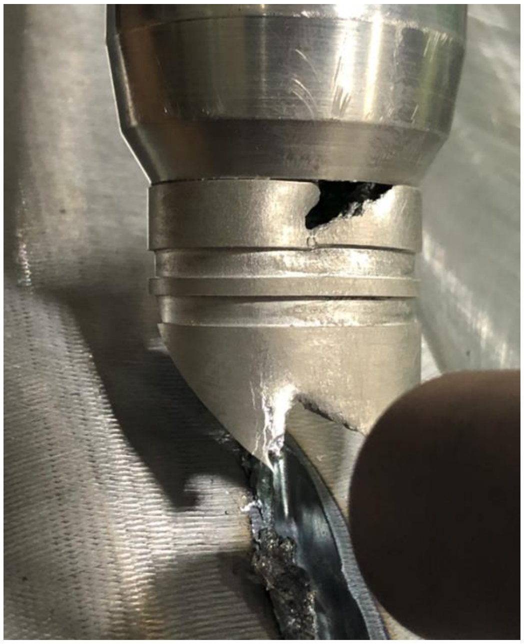

Figure 8. Melted tip with Significant Geometrical Changes to the Sip Port

For multiple trials, the initial gouging run would operate well, but the sip port was significantly changed by the end of the gouge. When attempting to initiate a subsequent gouge, the altered geometry of the sip port would change the air flow dynamic which would often inhibit the arc from initiating. If initiated, it would often extinguish the arc within the first inch of travel as the gouge would dig very deep and have too long of an arc gap for the power supply to maintain.

Figure 9. Successful Gouge Followed by Failed Initiation Attempts

Throughout multiple trials, the material that was gouged and sucked into the torch would stick and collect to the inside of the torch body building up to the extent that the entire inner diameter (ID) of the torch would be blocked off causing a near complete loss of suction, Figure 10. This blockage limited the length of gouge that EWI was able to execute to 2 ft.

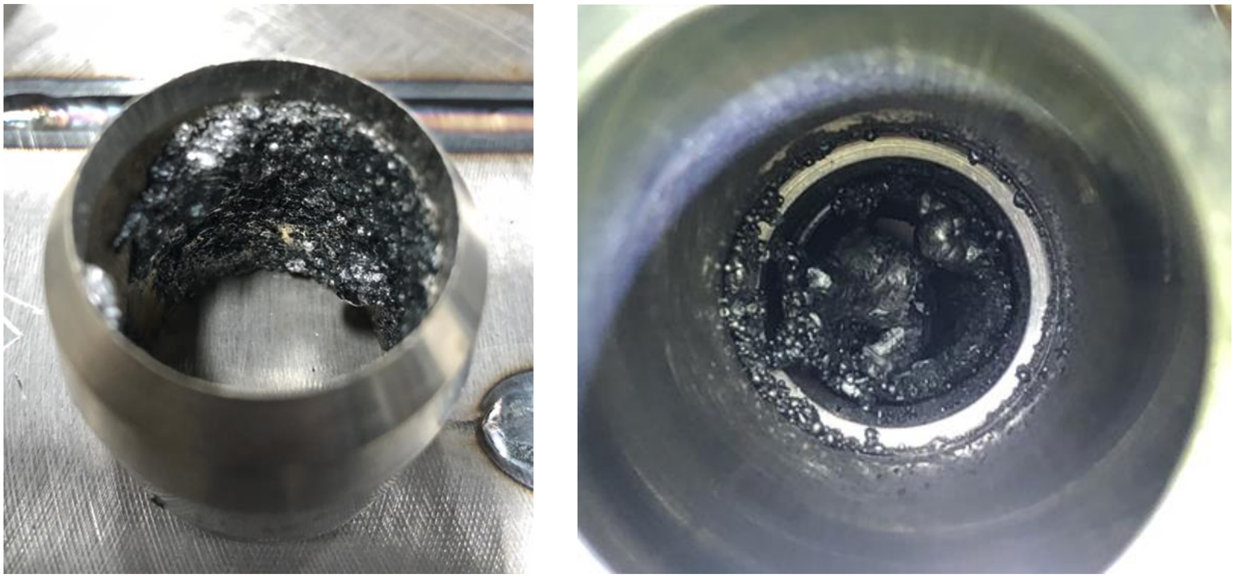

Figure 10. Gouged Metal that has Caught in the Torch Components and Clogged the System

When Mr. Klangos delivered the WeldVac system to EWI there was only a small supply of approximately 10 tips. It was communicated upon system delivery to EWI that these tips readily melt and deteriorate at the sip port when gouging and need to be often replaced. The longest run that Mr. Klangos claimed to have performed was a 6-ft gouge. This was with the aid of a water-cooling mechanism that was not used for this project as it provided direct water contact and the possibility of residual hydrogen entrainment in the base material. At that point in the project, Mr. Klangos did not have a 3D CAD model or 2D drawings of the tips so one tip was selected to be reversed engineered and used the basis to fabricate more. A model and corresponding drawing were created and a batch of 50 tips were fabricated. Further into the project, Mr. Klangos questioned if the tips that he initially delivered to EWI were the correct and latest design and he realized that these tips were not. He was able to then provide a 3D CAD model and EWI had an additional 50 tips manufactured according to this updated tip design. Once fabricated, EWI ran multiple trials with the new tips, but they did not produce much better results than with the tips of the initial design. Some better success was found with the new tip design when the parameters were reduced to produce smaller gouges. EWI was able to make 2-ft long gouges with the original three-piece WeldVac torch design to produce small gouges that had consistent geometry along the length of the gouge and low amounts of surface oxidation, Figure 11. After a 2-foot gouge was made, the torch was cleaned to remove clogging that had built up. Table 1 shows the system parameters used make these gouges with the three-piece torch.

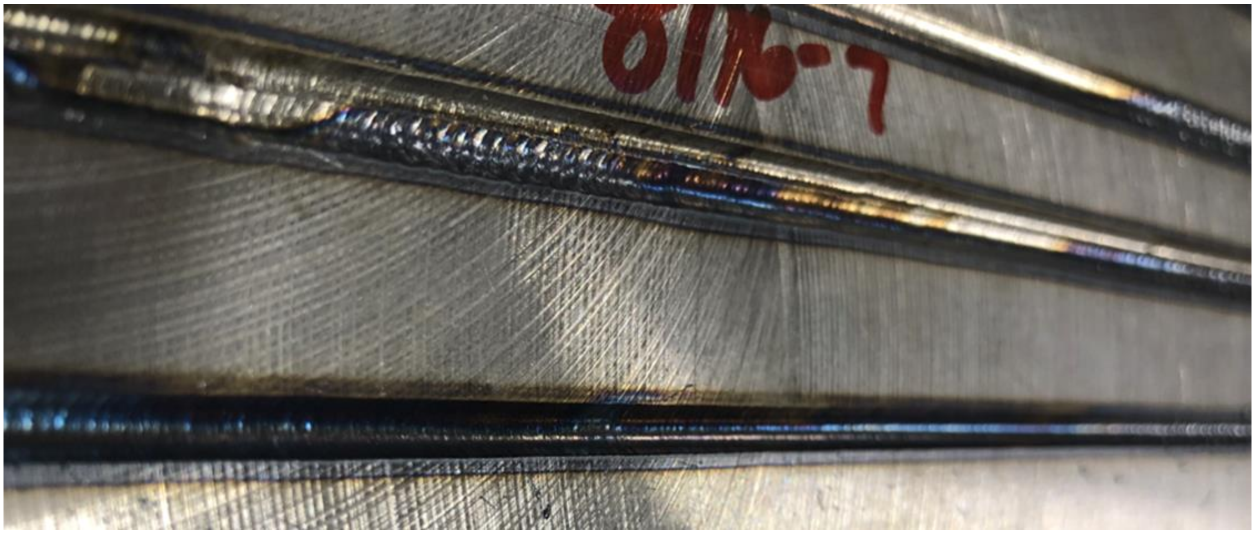

Figure 11. Successful Small Gouges with Three-Piece Torch

Table 1. Three-Piece Torch DH36 Steel Gouge Parameters

Alloy	Shielding Gas Composition	Shielding Gas Flow Rate (CFH)	Welding Current (A)	Welding Polarity	Travel Speed (IPM)	Gouge Width (inch)	Gouge Depth (inch)
DH36 Steel	100% Argon	70	125	DCEN	24.2	0.16	0.06

EWI made some simple modifications to the torch design in an effort to reduce melting of the sip port and clogging in the torch. This was accomplished by reducing the complexity of the three-piece torch to a single one-piece torch design, Figure 12. The ID of the torch at the tip region was significantly larger compared to the region of the three-piece torch. Because it is made of a single tube of aluminum, the sip port experienced less melting due to the enhanced heat sync of the single-piece torch. This new torch design was able to make a larger gouge than the three-piece torch, but it still clogged and needed to be cleaned out at the end of every 2-ft gouge run.

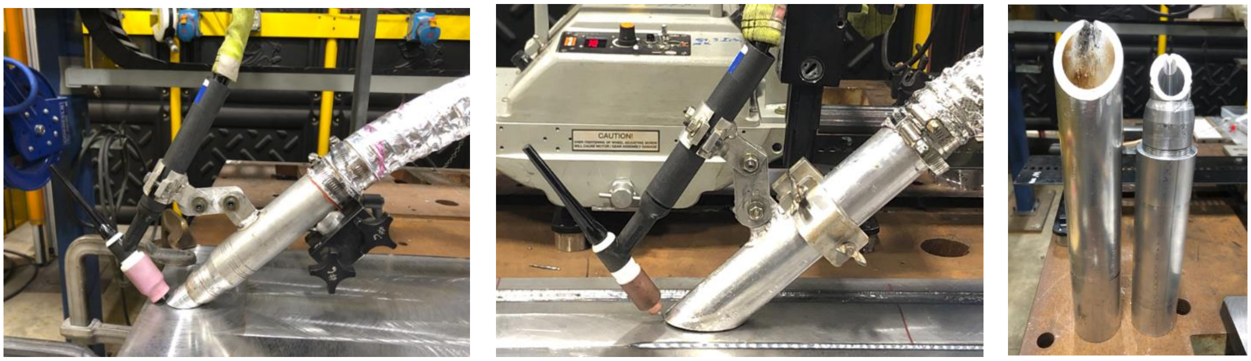

Figure 12. Original WeldVac Three-Piece Torch (right) **and Modified One-piece Torch** (left)

The one-piece torch was able to produce larger gouges than the three-piece torch but with similar good results of exhibiting gouges with consistent gouge geometry along the entire length of a gouge and low amounts of surface oxidation, Figure 13. A wider excavation was achieved by running subsequent gouges that are offset to the side by a distance of 50% of the original gouge width. An excavation 1-in. wide was produced by using this stepover method, Figure 14. For some of these stepover gouge passes, the GTAW torch created a liquid weld pool, but the suction air flow just moved it over within the excavation cavity solidifying in slag form and did not remove it through the torch body and extraction hose. This slag was readily removed by hand after it was loosened by a hammer. **Error! Reference source not found.** shows the system parameters used make these gouges with the one-piece torch.

Figure 13. Single Gouge with One-Piece Torch

Figure 14. Excavation by Multiple Single-Pass Gouges

Table 2. Three-piece Torch DH36 Steel Gouge Parameters

Alloy	Shielding Gas Composition	Shielding Gas Flow Rate (CFH)	Welding Current (A)	Welding Polarity	Travel Speed (IPM)	Gouge Width (inch)	Gouge Depth (inch)
DH36 Steel	100% Argon	70	225	DCEN	15.9	0.22	0.08

While the one-piece torch was able to produce a larger gouge than the three-piece torch, it was still subject to similar clogging issues. At the end of a 2-ft run, the torch would need to be cleaned to remove clogging buildup. Figure 15 shows typical clogging buildup at the end of a 2-ft run on steel base plate. It is simpler to remove clogged slag from the one-piece torch than from the three-piece torch as it has a larger inner diameter, does not have stepped transitions between component interfaces, and has no internal thread for debris to hang up on. For the current design, the torch is best cleaned by removing the extraction hose and removing debris through access at the back of the torch, Figure 16.

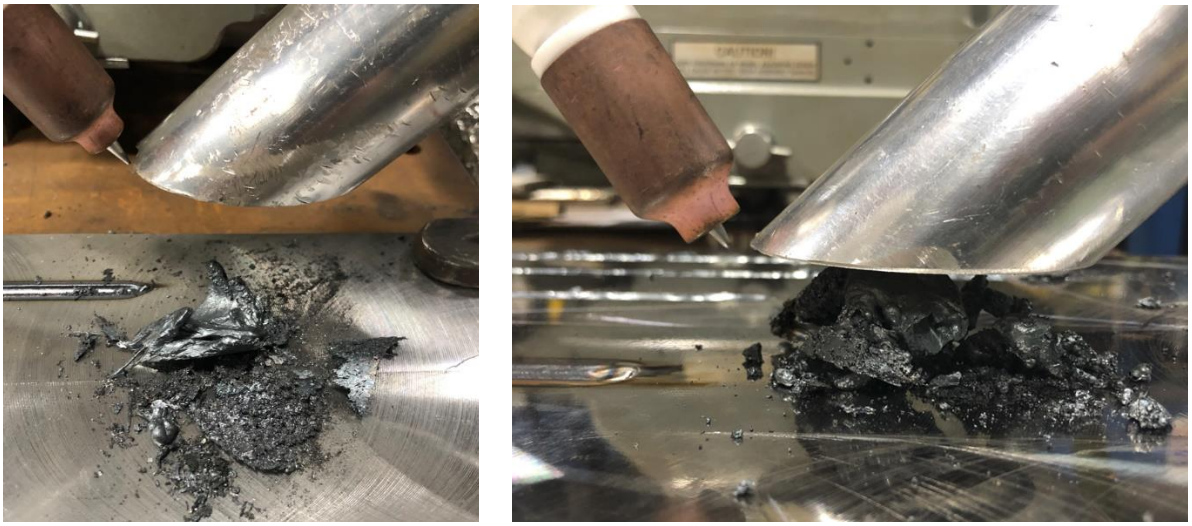

Figure 15. Typical Clogging in the One-piece Torch

Figure 16. Typical Clogging in the One-piece Torch

4.3 **Task 3 – Demonstration and Implementation**

EWI traveled to Vigor shipyard in Seattle, Washington, to demonstrate the WeldVac system and share with shipyard personnel the development progress made throughout the project. DH-36 steel plates used during development activities with a variety of gouge sizes and length were brought to aid in communicating the work complete to date and to show the capabilities of the system. The WeldVac system was assembled at the shipyard training facility, and an overview of system components and functions was reviewed. A single gouge on DH-36 steel plate was demonstrated and discussed Figure 17. The shipyard personnel expressed interest in applying the WeldVac system to alloys other than steel for the remainder to allotted demonstration time. Copper-nickel and aluminum alloys were selected, and remnant scrap pieces around the facility were gathered for trials.

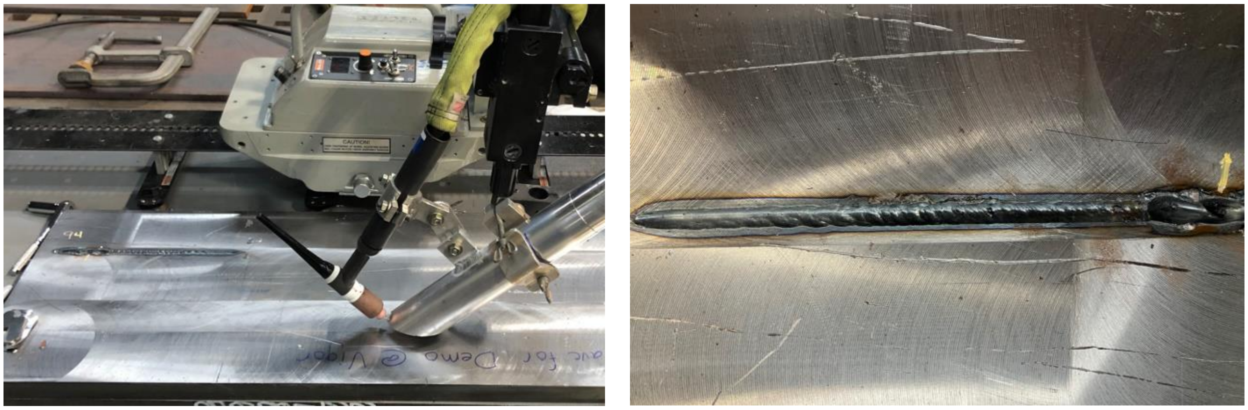

Figure 17. Single Gouge Pass on DH36 at Vigor Shipyard Demonstration

A gouge on 70-30 Copper-Nickel (Cu-Ni) was made using the same setup and parameter as DH36 steel gouges as a starting point, Figure 18. The initial trial produced a gouge, but it was heavily oxidized, had an irregular contour, and slag buildup at the edge of the gouge.

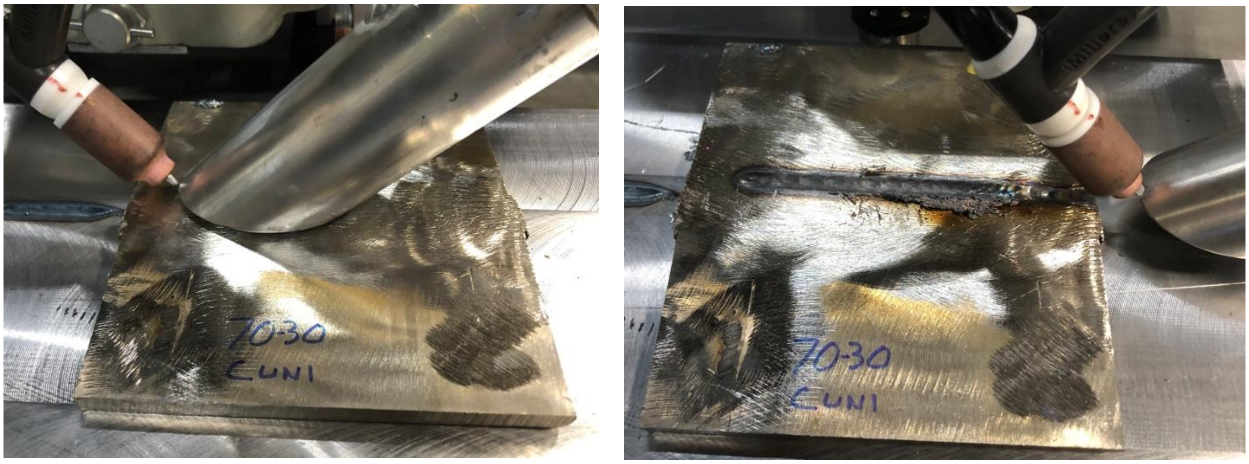

Figure 18. Initial Gouge Trial on 70-30 Cu-Ni

Prior to the next trial, the torch was adjusted for alignment, and the containment box valve was fully opened to reduce suction at the torch. On this subsequent Cu-Ni trial, the gouge ran similarly to the first trial for the first half producing a gouge of irregular geometry but then improved for the second half exhibiting regular geometry and no surface oxidation, Figure 19. The gouge improved once the torch started to pass over the end of the plate. Suction at the sip port was reduced as the torch passed over the end of the plate, so the conclusion was made that the vacuum suction was too high for the first half of the gouge leading to irregular geometry, heavy oxidation, and slag adhering to the surface of the plate.

Figure 19. Initial Gouge Trial on 70-30 Cu-Ni

With the valve on the containment box fully open there was no more built-in adjustment to further restrict the amount of air flow through the torch. The exhaust port on the shopvac weld was 50% closed with tape to reduce the efficiency of the vacuum and, therefore, reduce intake airflow. A gouge was made with this setup which produced good, consistent geometry with just heat-tint oxidation, Figure 20. The gouge was lost for the last 1-in. of travel as the torch traveled past the edge of the plate reducing the suction at the sip port to a level not sufficient to continue extracting the molten weld pool.

Figure 20. Second Gouge on 70-30 Cu-Ni

The 100% argon shielding gas was exchanged for 75% helium-25% argon shielding gas to observe the influence of greater thermal arc energy for a given parameter set. A plate of 90-10 Cu-Ni replaced the 70-30 Cu-Ni plate used for previous samples as there was no longer room for any more gouging runs. The initial gouge produced consistent geometry but with a heavier oxide film than just a heat-tint oxidation layer, Figure 21. This oxidation layer would be readily removed by a light sanding or grinding process. A second gouge was made at the same parameters to observe a simple level of repeatability. The second gouge performed identically to the first gouge. Table 3 shows the system parameters used make these Cu-Ni gouges with the one-piece torch.

Figure 21. 90-10 Cu-Ni Gouges Using 75% Helium- 25% Argon Shielding Gas

Table 3. One-Piece Torch Cu-Ni Gouge Parameters

Weld ID	Alloy		Shielding Gas Composition	Shielding Gas Flow Rate (CFH)	Welding Current (A)	Welding Polarity	Travel Speed (IPM)	Gouge Width (inch)	Gouge Depth (inch)
1		70-30 Cu-Ni	100% Argon	65	225	DCEN	15.9		
2									
5								0.208	0.08
10		90-10 Cu-Ni	75% Helium 25% Argon					0.24	0.095
11								0.25	0.108

The Cu-Ni exhibited the typical clogging issue that was observed with gouging on steel. Debris was primarily accumulating in the aluminum torch body, with some debris collecting in the flexible silicon vacuum hose where it connected to the end of the torch body.

Experimental gouge trials were also conducted on a remnant plate of 5086 aluminum. The initial trial used the same setup and parameters as that of the as DH36 steel gouges as a starting point but with the 75% helium-25% argon shielding gas that was already plumbed from the Cu-Ni trials. The result was a heavily oxidized gouge with an irregular surface, Weld #1 in Aluminum. Subsequent trials experimented with alternating current with a 50% EN-50% EP balance which produced a cleaner gouge but did so with irregular geometry and elevated heating and melting of the WeldVac torch body. Further gouge trials were made with alternating current at varying current levels and travels speeds, but none achieved desirous results.

Figure 22. Gouge Trials Made on 5085 Aluminum

Positive gouge results were achieved when the shielding gas was switched to 100% argon using alternating current with a 50/50 polarity balance, Weld #10 and #11 in Figure 23. These gouges exhibited consistent geometries and relatively clean surfaces free from heavy oxides. Welds #10 and #11 were run using the same conditions and parameters which show a simple degree of good repeatability. Table 4 shows the system parameters used make these aluminum gouges with the one-piece torch.

Figure 23. Good Gouges Made with 100% Argon Shielding Gas

Table 4. One-Piece Torch Aluminum 5086 Gouge Parameters

Weld ID	Alloy	Shielding Gas Composition	Shielding Gas Flow Rate (CFH)	Welding Current (A)	Welding Polarity	Welding Polarity Balance (%)	Travel Speed (IPM)	Gouge Width (inch)	Gouge Depth (inch)
1	5086 Aluminum	75% Helium 25% Argon	65	225	DCEN		15.9		
2				225	AC	50			
3				275					
4				275					
5				150	DCEN				
6				150			7.7		
7				200			12.3		
8		100% Argon		200				0.199	0.088
9				275				0.254	0.196
10				275	AC	50		0.27	0.073
11				275			15.9	0.273	0.073

Parameters that yielded positive results from the aluminum trials were then deployed on a mock aluminum weld reinforcement removal scenario. A remnant 5xxx series aluminum plate was located that had a weld reinforcement of 0.125 in. from a previously deposited groove weld. Five individual gouges were made on this reinforcement area with each gouge pass being stepped over by half of the gouge width to produce an excavation, Figure 24. After the fifth gouge was complete the weld reinforcement had been removed over a length of 6 in. Each of the individual gouges produced consistent geometry and a surface finish free from heavy oxides. The bottom of the gouge excavation had slight undulations from the five gouge passes but overall produced a relatively flat profile, Figure 25. Table 5 shows the system parameters used make the aluminum excavation gouges with the one-piece torch to remove the weld reinforcement.

Figure 24. Weld Reinforcement Removal from Aluminum Plate

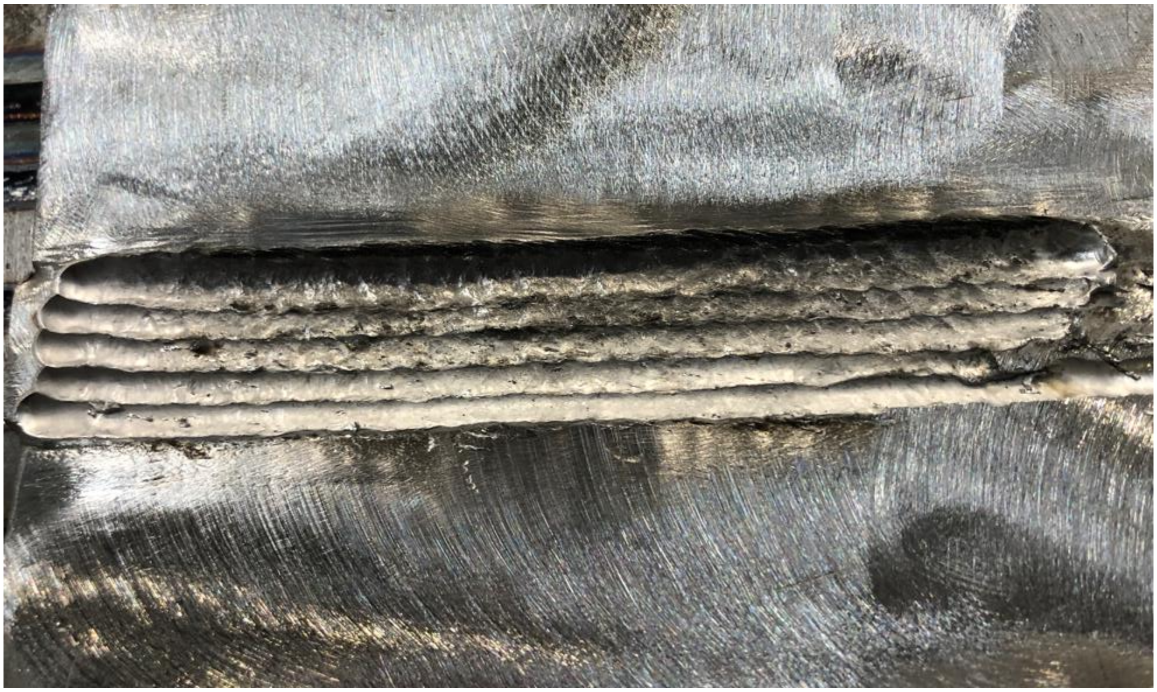

Figure 25. Complete Weld Reinforcement Removal from Aluminum Plate

Table 5. One-Piece Torch Aluminum 5XXX Excavation Gouge Parameters

Alloy	Shielding Gas Composition	Shielding Gas Flow Rate (CFH)	Welding Current (A)	Welding Polarity	Welding Polarity Balance (%)	Travel Speed (IPM)	Gouge Width (inch)	Gouge Depth (inch)
5XXX Aluminum	100% Argon	65	275	AC	50	15.9		

An experimental trial was made on the seam of two 5086 aluminum plates to simulate a back-gouging process on a square groove butt joint, Figure 26. The two plates were clamped to the table to keep them from moving during the gouging process. The resulting gouge produced consistent cross-sectional geometry along the entire length, was free from heavy oxides, and produced a good, consistent radius despite having a faying surface gap between the two plates at the bottom of the gouge, Figure 27 and Figure 28. Table 6 shows the system parameters used make the aluminum back-gouge pass with the one-piece torch.

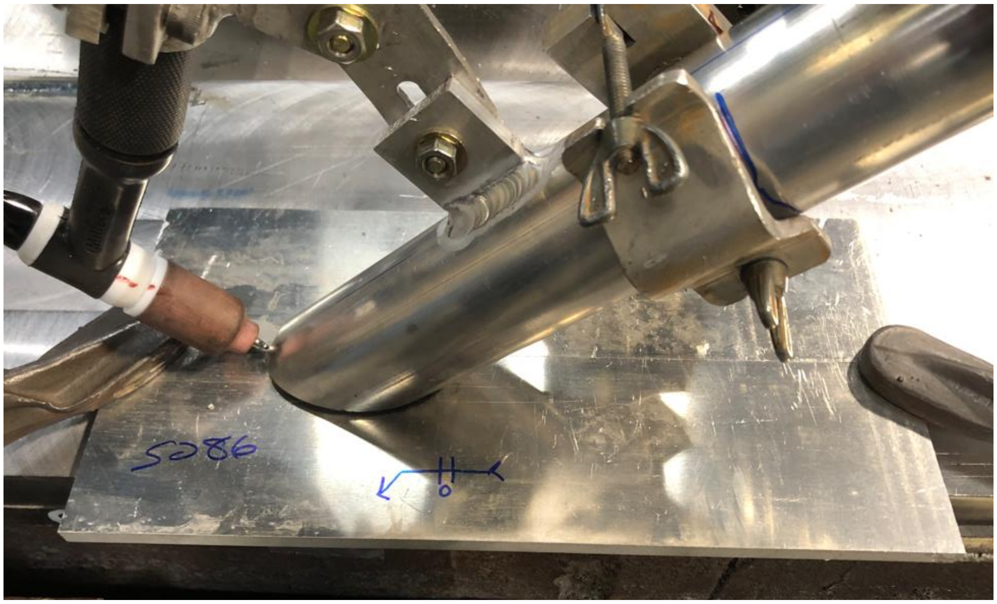

Figure 26. Plate and Torch Setup for a Back-Gouging Trial on 5086 Aluminum Plate

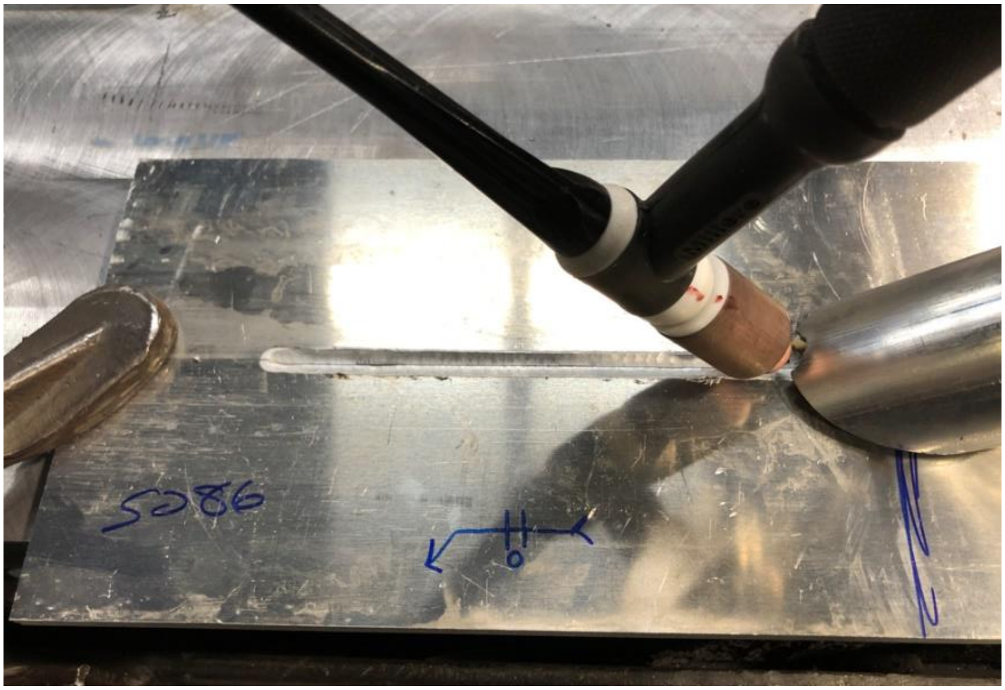

Figure 27. Back-Gouged Trial on 5086 Aluminum Plate

Figure 28. Back-Gouged Groove Trial on 5086 Aluminum Plate

Table 6. One-Piece Torch Aluminum 5XXX Back-Gouge Parameters

Alloy	Shielding Gas Composition	Shielding Gas Flow Rate (CFH)	Welding Current (A)	Welding Polarity	Welding Polarity Balance (%)	Travel Speed (IPM)	Gouge Width (inch)	Gouge Depth (inch)
5XXX Aluminum	100% Argon	65	275	AC	50	15.9	0.282	0.081

The aluminum trials exhibited clogging issues, but debris collected more heavily in the flexible silicon vacuum hose where it connected to the end of the torch body than in the torch body components. This clogging area was the opposite for the steel and Cu-Ni gouges, which collected more in the torch body components than the flexible silicon vacuum hose.

4.4 Task 4 – Technology Transfer and Reporting

EWI presented project overview and progress presentations at the following technology transfer events:

- March 2023 – NSRP All Panel Meeting
- July 2023 – NSRP Workforce and Compliance Panel Meeting
- September 2023 – FabTech

EWI submitted quarterly reports to ATI that provided both project management updates and technical updates. Additionally, this report serves as the final written Microsoft Word report that documents the background, technical approach, results, and conclusions of the work performed.

5.0 Discussion

Starting with discussions with Mr. Klangos at system delivery to EWI and continuing through the demonstration at Vigor Shipyard, there are a number of design considerations that need to be addressed and re-engineered for WeldVac to be commercially hardened and ready for deployment in industry. The following is a list of these design considerations:

- The tip is made of 6061-T6 aluminum, and the intense heat of the electrical arc and molten weld pool causes the geometry around the sip port to melt and erode. An ideal air flow through the sip port plays a major role in promoting a good gouge that has consistent geometry and little to no surface oxides. As the sip port melts and erodes, that air flow dynamic changes easily towards a non-ideal flow and results in a poor gouge. The tip must be made from a material that can withstand the heat of the arc and weld puddle and maintain a consistent sip port geometry. It was observed that the sip port on the one-piece torch design withstood a much greater time of gouging than the sip port on the tip of the three-piece torch design. This can likely be attributed to the greater heat sink capability of the one-piece torch design.
- The system was supplied with a three-piece piece torch design that consisted of the torch body, nozzle adapter, and tip with integrated sip port.
    - The connection between the torch body and nozzle adapter is an aluminum threaded connection. The threads on many of these assembles became galled and compromised and could no longer be used. This is likely due to the soft physical property of aluminum along with the thermal expansion that the threads were subjected to during gouging runs. If a threaded connection is to be maintained, the material and/or thread size/pitch will need to be changed so that thread seizure and galling are not an issue.
    - The connection between the nozzle adapter and the tip is a press fit connection. Often this fit was either too tight – necessitating the sanding the interface on the tip so they would fit together – or it was too loose and would sometimes loosen further due to thermal expansion during a gouge. This connection would need to be redesigned so the parts fit readily together and stay assembled throughout a gouging run.
    - There are stepped features on the ID of the torch assembly at the interface between the torch body and nozzle adapter and between the nozzle adapter and the tip. These areas exhibited a greater propensity for clogging to initiate and build out from that builds up to the point of negatively affecting the gouge. If a multi-piece torch design is to be used, the ID transitions between components need to be smooth and not stepped.

- Mr. Klangos of WeldVac communicated that the high-temperature silicon exhaust hose was wrapped in aluminum foil tape to prevent the silicon exhaust hose from melting. Even with this measure, the silicon hose would still overheat and degrade over the course of multiple gouges. There was a propensity for molten metal droplets to impact the silicon hose where it attached to the back end of the torch body and bond to the silicon or wire reinforcement embedded within the silicon hose. This then promoted further debris collection in this area resulting in more clogging. A higher temperature hose solution that resists the adherence of impacting molten metal droplets would be needed to have better longevity.
- The valves on the containment boxes were either gate style or ball valve style. Neither of these had an indicator to confirm the amount the valve was opened or closed. These did not provide enough control of air flow through the torch.
- The vacuum motor should be able to be controlled to a greater degree than just on/off. It would be more direct to have a singular path from the torch to the vacuum, first passing, of course, through the containment box, without a secondary valve opening on the containment box. To adjust the airflow and/or velocity, the vacuum motor would be adjusted instead of the valve on the containment box. For the Cu-Ni trials at the Vigor demonstration, the air flow suction needed to be reduced below what the valve on the containment box would allow. Having a larger range of suction adjustment at the vacuum itself would be necessary.
- An air flow sensor should be installed so that the exact volume and velocity of air flowing through the torch is known as it is a critical variable to system operation.
- Thermal sensors should be installed at various points in the exhaust path to monitor the exhaust component temperatures.
- The containment box should be changed so that the lid can be readily taken off and debris removed (i.e., snap latches).
- When hot material entered the water in the containment box, small amounts of steam were produced which was then sucked through the paper-based filter in the shopvac. This caused the filter to dampen and resulted in a loss of suction. If a filter is to be used in the vacuum path, it must be far enough from the containment box that moisture does not compromise the overall function of the system.
- To pursue applications in gouging to greater depths than just a single pass, the torch will need to be reduced in size significantly. Research and development efforts in establishing how small a WeldVac torch can be is advised.

6.0 Conclusions

1. The current WeldVac system is a successful reduction-to-practice alpha prototype model that shows the process can produce geometrically uniform gouges that are free or nearly-free of surface oxides under carefully controlled conditions. With that said, the WeldVac system is far from reaching a production-ready, commercially available status. The system will need to undergo further product development for refinement to get it to

this point. A list of the main changes was addressed in the Discussion portion of this report.

2. Under carefully controlled conditions in a laboratory environment, this project has shown that the WeldVac system can make good gouges on steel, stainless steel, Cu-Ni, and aluminum base materials.
3. The WeldVac system was shown to make single gouges as well as wider single layer excavations on steel and Cu-Ni base materials.
4. Specific applications within shipbuilding have been identified that would benefit from utilizing a yet-to-be matured WeldVac system. This is likely the same across other industries, where the existence of specific applications where the deployment of a matured WeldVac system would be of great value.
5. The WeldVac system will likely show itself to be superior to CAG in reduced noise and process fume generation once a torch is developed that can function without clogging or degrading due to melting.

7.0 Recommendations

Personnel at the Vigor shipyard recommended three applications that WeldVac could be of great benefit to the shipyard after undergoing further product development.

The first application is the removal of fairwaters and rope guards that encase the space between the end of shaft struts and the propellers. The parts are typically made of 70/30 or 90/10 Cu-Ni and are approximately 1-in. thick. These components are toned to be removed whenever a propeller shaft is pulled for inspection, repair/overhaul, or replacement. The current means of removal is by cut-off disk or reciprocating saw. Before reinstalling and being welded back in place after work on the shaft is complete, a bevel edge on each cut surface is made using hand grinders. Both the initial removal and formation of a bevel prep are time consuming processes that involve the dispersal of hot material (i.e., sparks from grinding) that limits others from working in that area. WeldVac was identified as a possible process alternative to cutting through the rope guard and formation of the bevel prep. The two tasks could potentially be accomplished simultaneously. An excavation could be made that starts wide and then tapers down in width as it makes its way through the 1-in. thick part. This would be accomplished by multiple side-stepped gouges over multiple layers. Eventually, the two tapered walls could converge upon each other at the 1-in. depth where it would finally break through the other side and sever the part, accomplishing both the part separation and the bevel prep in one operation.

The following design considerations would need to be satisfied in order for WeldVac to be deployed on the fairwater rope guard application (these are in addition to the design consideration listed in Section 5):

- The WeldVac system would need to be adapted into a hand-held torch as this application is not suited for a fully mechanized solution.
- The WeldVac system would need to operate consistently in all positions and progressions:
    - Flat
    - Horizontal
    - Vertical down
    - Overhead
    - Vertical up.
- The WeldVac system would need to be able to go progressively deeper to produce a gouge of desired depth while producing beveled walls at approximately 20-30 degrees.
- The WeldVac system would need to be able to make a gouge that is 7-ft long.

Carbon arc gouging cannot be used on Cu-Ni alloys, so WeldVac would only compete against cut-off disk on angle grinders and reciprocating saws for this application.

The second application would be to remove weld reinforcement on aluminum butt joint welds joining ship deck plates. The aluminum weld reinforcement is currently removed by means of grinding and sanding. The height of weld reinforcement is approximately 1/8-in. high and can be up to 1 in. in width. This application could be performed with either a hand-held or mechanized torch configuration. Similar to Cu-Ni alloys, CAG cannot be used on aluminum alloys, so, again, WeldVac would only compete against grinding and sanding operations.

The third application is the removal of fillet welds in steel t-joint and deeper gouging capabilities when said operations need to be done in an environment that has high-value equipment (i.e., computer systems). Significant time savings would benefit the shipyard if equipment “cover-up” time was reduced. Vigor personnel communicated that this would be the one area that WeldVac could compete against the CAG process when gouging on steel. The following design considerations would need to be satisfied for WeldVac to be deployed on this application (these are in addition to the design consideration listed in Section 5):

- The WeldVac system would need to be adapted into a hand-held torch, as this application is not suited for a fully mechanized solution.

- The WeldVac system would need to operate consistently in all positions and progressions:
    - Flat
    - Horizontal
    - Vertical down
    - Overhead
    - Vertical up.
- The WeldVac system would need to be able to go progressively deeper than a single pass on a flat plate application.
- The WeldVac system would need to be able to remove a large fillet weld over the course of multiple gouging runs instead of attempting to remove an entire fillet weld with one gouging run.

8.0 Disclaimer

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