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Vacuum Gas Tungsten Arc Welding
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EXECUTIVE SUMMARY

The Rocketdyne Division of Rockwell International conducted a program for the National Aeronautics and Space Administration - Marshall Space Flight Center entitled "Vacuum Gas Tungsten Arc Welding". This two phase program was performed under NASA Contract NAS8-39932 as part of the NASA Research Announcement, NRA-92-MSFC-1. The worked performed during Phase I is summarized and the Phase II effort is presented in detail.

This two year program investigated Vacuum Gas Tungsten Arc Welding (VGTAW) as a method to modify or improve the weldability of normally difficult-to-weld materials. VGTAW appears to offer a significant improvement in weldability because of the clean environment and lower heat input required. The overall objective of the program was to develop the VGTAW technology and implement it into a manufacturing environment to lower cost and improve quality and reliability for aerospace components for the space shuttle and other NASA space systems.

Phase I of this program was aimed at demonstrating the process's ability to weld normally difficult-to-weld materials. Phase II focused on further evaluation, a hardware demonstration and a plan to implement VGTAW technology into a manufacturing environment.

During Phase I, the following tasks were performed:

- Task 11000 Facility Modification. An existing vacuum chamber was modified and adapted to a GTAW power supply.

- Task 12000 Materials Selection. Four difficult-to-weld materials typically used in the construction of aerospace hardware were chosen for study.

- Task 13000 VGATW Experiments. Welding experiments were conducted under vacuum using the hollow tungsten electrode and evaluated. As a result of this effort, two materials, NARloy Z and Incoloy 903, were downselected for further characterization in Phase II.

- Task 13100 Aluminum-Lithium Weld Studies. This task was added to the original work statement to investigate the effects of vacuum welding and weld pool vibration on aluminum-lithium alloys. It was completed as part of Phase I.

During Phase II, the following effort was performed

- Task 21000 Materials Characterization. As a result of parameter study, Incoloy 903 welds were produced without microfissures. Studies to produce welds in NARloy Z did not prove to be successful.

- Task 21200 - Materials Characterization of Oxygen Compatible Coatings. The original program scope was modified to include an effort to fabricate NiCoCrAlY coatings for oxygen compatibility evaluation. Specimens were fabricated by vacuum plasma spray for promoted combustion, particle impact and frictional heating tests and delivered to NASA-MSFC.

- Task 22000 Hardware Demonstration. Incoloy 903 weld overlays were produced and evaluated. Overlays with no microfissures were produced.

- Task 23000 Technology Implementation Plan. A plan was developed and initiated at Rocketdyne to continue the development of this technology. Rocketdyne will continue to fund development of Incoloy 903 VGTAW to eliminate microfissures.

An overall schedule showing the time phasing is presented in Figure 1.

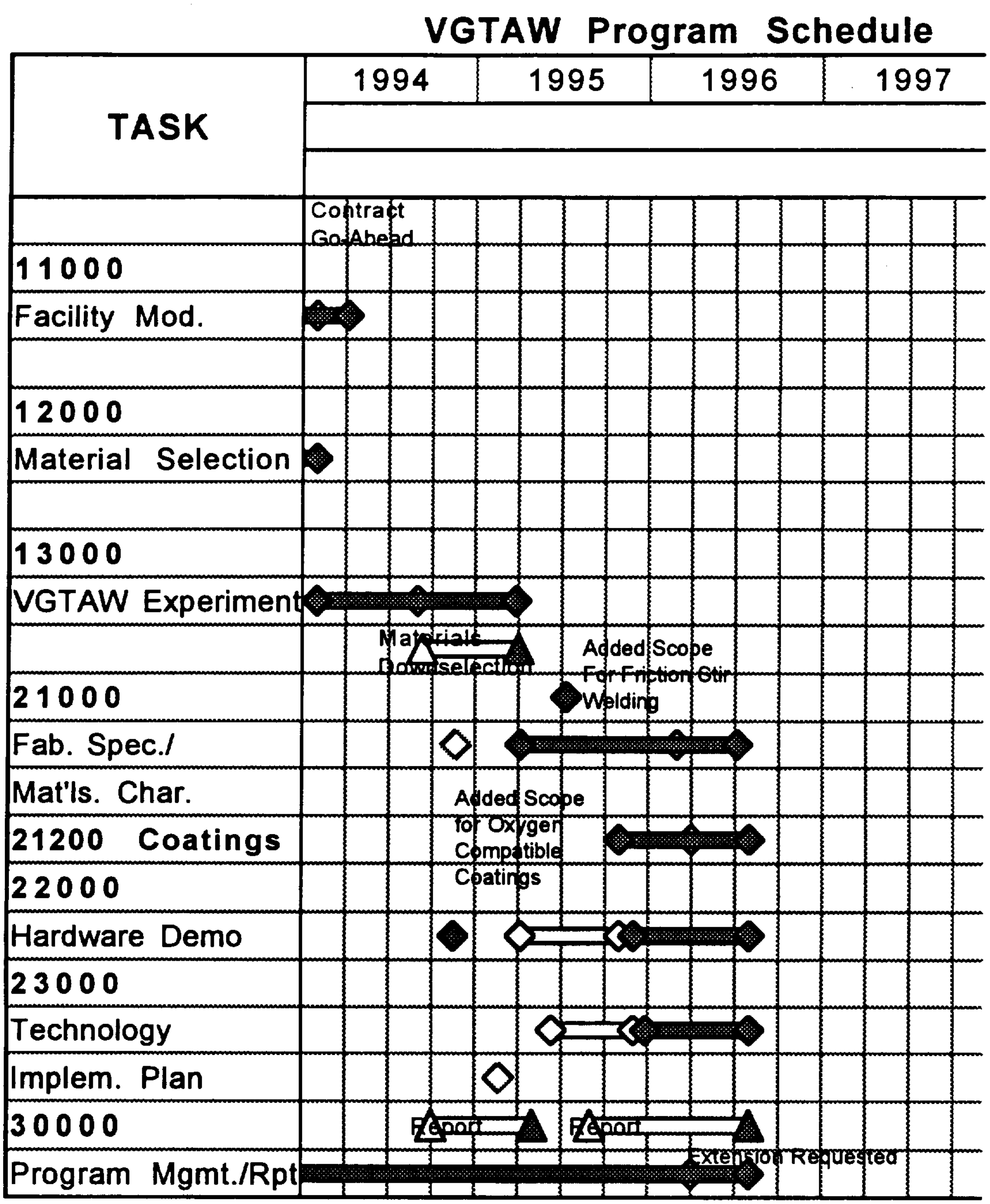


Figure 1. Overall Program Schedule for VGTAW Program.

INTRODUCTION

The design of aerospace hardware for propulsion systems and launch vehicles has been driven by performance and life, as illustrated by the Space Shuttle Main Engine (SSME). Typically, welded construction is utilized to join metallic components to minimize weight and produce leak-free joints; however, the materials of construction for such components have tended to be selected primarily based on their physical or mechanical properties or their chemical compatibility, e.g., hydrogen embrittlement resistance, and to a lesser degree on their fabricability. As a result, these materials frequently may not be robust to welding. For example, Incoloy 903, which is used extensively on SSME, is weldable but may develop undesirable microfissures. This class of material can be categorized as difficult-to-weld.

Rocketdyne is well aware of the difficulties involved in welding these types of materials and has been working for several years to improve the weldability of such materials. One of the potential solutions to solving some of these welding problems is to produce gas tungsten arc (GTA) welds in a vacuum environment. The vacuum environment provides an extremely clean atmosphere which minimizes contamination that may be present in conventional GTA welding. It has also been demonstrated that lower power is required when GTA welds are produced in a vacuum as opposed to under an inert environment. The ability to produce GTA welds in a vacuum had not been possible until the development of the hollow tungsten electrode. The principal difference between this and the normal solid tungsten electrode is that the gas flows down the center of the electrode instead of around the outside. This enables a stable arc to be maintained under vacuum. Schematics of conventional and hollow electrode vacuum GTA welding torches are shown in Figure 2.

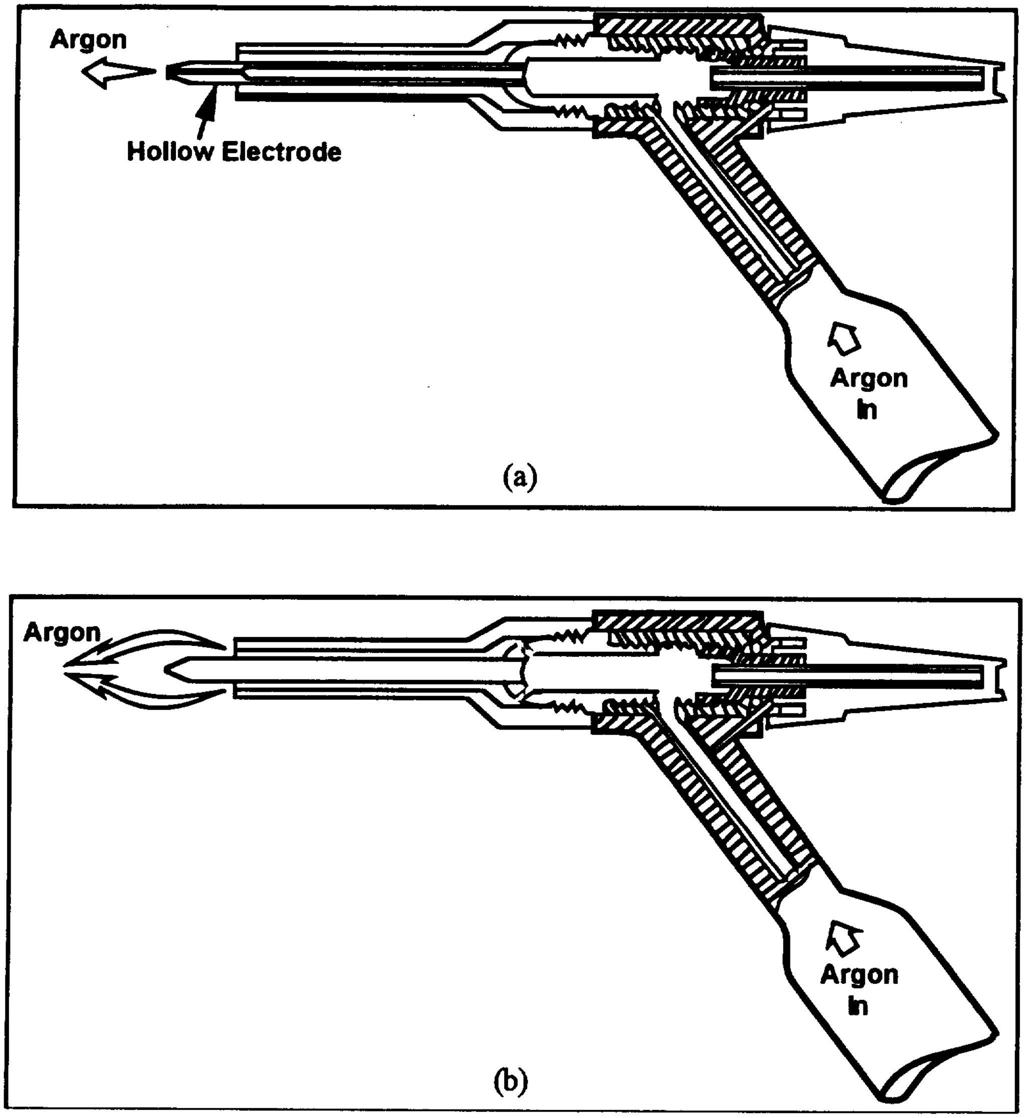


Figure 2. Vacuum (a) and Conventional (b) GTAW Torches

Rocketdyne has been developing the modified GTAW process since 1986 for use in space as a repair or assembly tool. Based on extensive experience with conventional GTAW in the fabrication of the SSME, it was felt that modifications could be made to stabilize the arc in vacuum. This was achieved by introducing a hole into the center of the nonconsumable tungsten electrode, and then, supplying inert gas through this hole. This modification proved successful in providing a stable arc under vacuum and led to the first GTA welds produced in a vacuum. Further, it was found that for a given welding current and electrode-to-work distance, the weld produced is both deeper and wider than that produced by conventional GTAW, indicating that process efficiency is increased. Continued development work demonstrated improved weld bead contour, increased penetration, and reduced energy input and inert gas consumption.

Complementary efforts by Rocketdyne and the NASA-MSFC produced system modifications that led to improvements in the torch design. The improvement was in the method of delivering gas onto the weld pool which resulted in better arc stability and reduced electrode erosion. A schematic of the improved VGTAW torch, which was patented (NASA Case# MSF-29766-1), is shown in Figure 3.

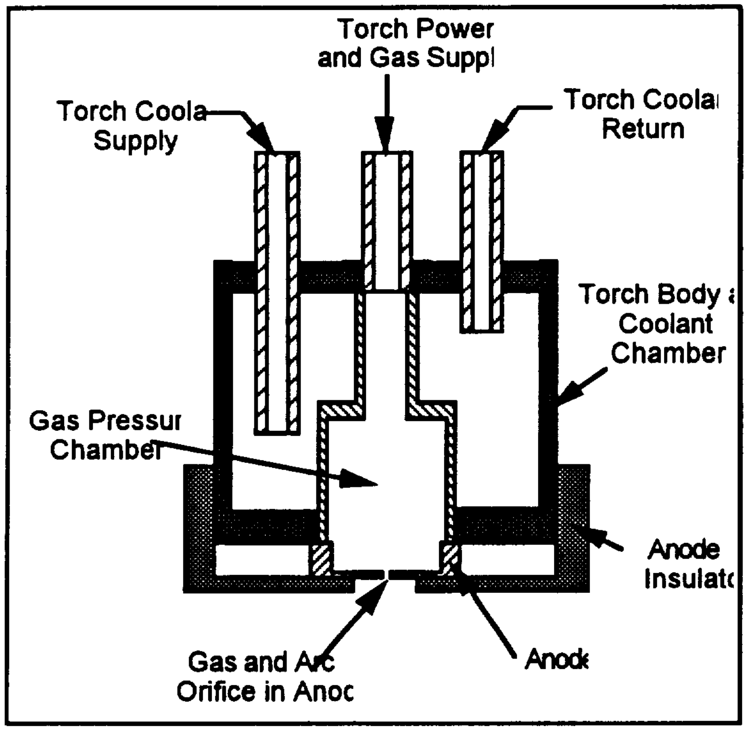


Figure 3. Improved Vacuum Gas Tungsten Arc Welding Torch

SUMMARY. PHASE I. TECHNOLOGY VALIDATION

The details of this effort was reported in the Phase I Report, Vacuum Gas Tungsten Arc Welding, Contract NAS8-39932, April 1995. The Phase I results are summarized herein. The objective of this study was to evaluate the VGTAW process on a variety of difficult-to-weld materials. The study investigated the effects of welding under a vacuum compared to welding under an inert environment. All welding experiments and evaluations were conducted at the NASA-MSFC Productivity Enhancement Center.

Task I1000. Facility Modification

The objective of this task was to set-up a facility for conducting the VGTAW experiments. The vacuum system used for process demonstration at the MSFC required modifications since it had been set-up originally to study vapor deposited coatings. The following modifications were performed prior to initiating the VGTAW experiments:

- Designed and fabricated a new gas management system which consisted of a digital mass flow meter, precision low flow rotometer and a precision needle valve.
- Modified and integrated a programmable three axes positioning device to manipulate the parts during welding.
- Designed and fabricated a new welding torch and chamber feedthrough.

A schematic of the entire, modified VGTAW system is shown in Figure 4.

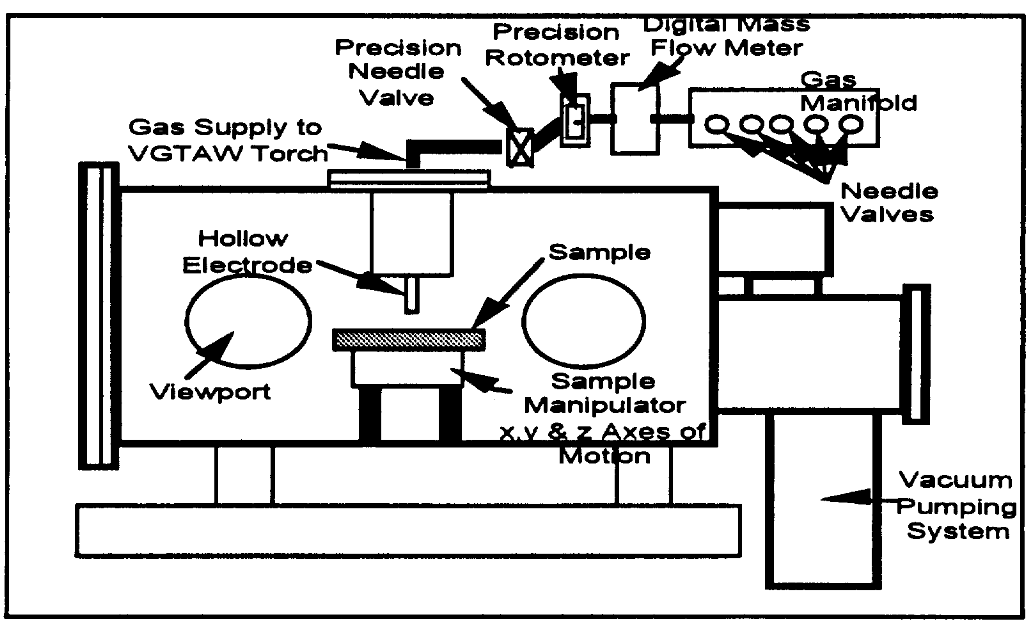


Figure 4. Schematic of the Modified VGTAW System

The system modifications allowed for the evaluation of the VGTAW process. The system pumping capacity, gas flow regulation into the chamber and electrode geometry are critical to the process.

The hardware and software modifications were tested during Phase I of this program. However, additional system modifications were identified during Phase I, (i.e., improvements to the gas regulation system) and were addressed in Phase II of this program. This effort has defined the guidelines that allow an ionizing arc to be initiated and maintained in a vacuum environment.

Task 12000. Materials Selection

The objective of this task was to select "difficult-to-weld" materials for VGTAW experiments. Material candidates for weld studies were based on their difficulty-to-weld using conventional gas tungsten arc processes along with their applicability to NASA's mission, for example, the Space Shuttle Main Engine (SSME) and Space Shuttle Super Light Weight External Tank. The selection process considered welding problems that could be attributed to atmospheric influence and joining process characteristics. On the basis of these criteria the following materials were selected for evaluation:

- NARloy-Z
- Incoloy 903 Overlays
- Inconel 718 Casting
- Aluminum-Lithium

Task 13000. VGTAW Experiments and Downselection

The objective of this task was to conduct the VGTAW parameter development for the selected materials and select the most promising candidates. Critical parameters, such as, power, vacuum levels, gun-to-work distance, etc. were studied. Initial weld parameter selection was based on Rocketdyne's experience with conventional GTAW.

Evaluation of the welded specimens included metallography and microhardness measurements. Metallographic specimens were prepared from each weld sample at several locations and analyzed for defects and other anomalies.

<u>NARloy-Z</u>

NARloy-Z was selected because it is considered extremely difficult to weld repair using the standard GTAW and Variable Polarity Plasma Arc Welding processes. The ability to weld repair NARloy-Z material may allow extended use of the SSME Main Combustion Chambers (MCC).

Inert gas and vacuum GTA welds were made on 0.100 in. NARloy-Z plate in the as-rolled condition. The NARloy-Z inert gas- and vacuum-produced weld samples were fabricated and metallurgically evaluated. After the first sample set was evaluated, two more inert gas GTA welds were fabricated to duplicate the shallow and full penetration welds produced using VGTAW. Table 1 shows the weld parameters used for each condition.

Table 1. NARloy-Z Vacuum and Conventional GTA Weld Parameters

Condition	Vacuum Level	Ar Gas Flow	Amps	Travel Speed	Penetration
Vacuum	2 millitorr	10 ccm	45	8 in./min.	Shallow
Vacuum	2 millitorr	10 ccm	75	8 in./min.	Full
Atmosphere	1 atm	35 cfh	150	3 in./min.	Shallow
Atmosphere	1 atm	40 cfh	150	1 in/min.	Full

These welds were cross sectioned and Knoop hardness measurements were taken as a function of position across the welds. The measurements are plotted in Figures 5 and 6. In both cases, shallow and full penetration, the hardness of both types of welds are very similar. As would be expected, the hardness drops, from that found in the fine grained base metal, across the heat affected zone and then increases in the weld due to the fast cooling rates.

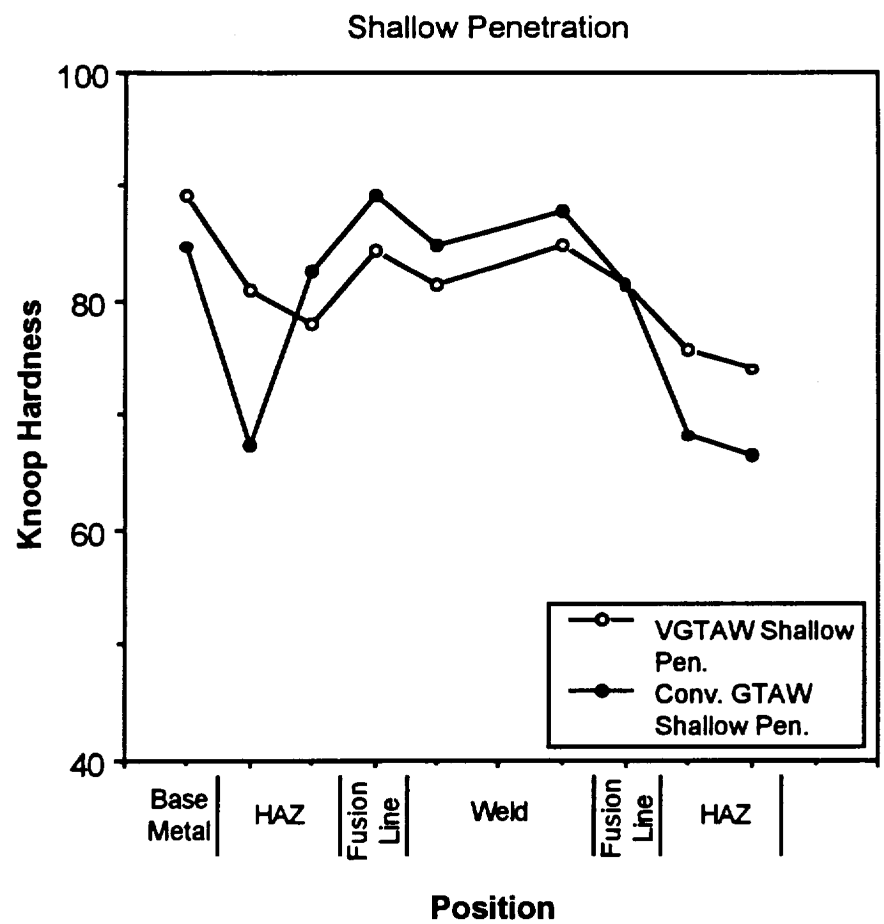


Figure 5. Hardness of VGTAW and Conventional Weld on Shallow Penetration Welds in NARloy Z.

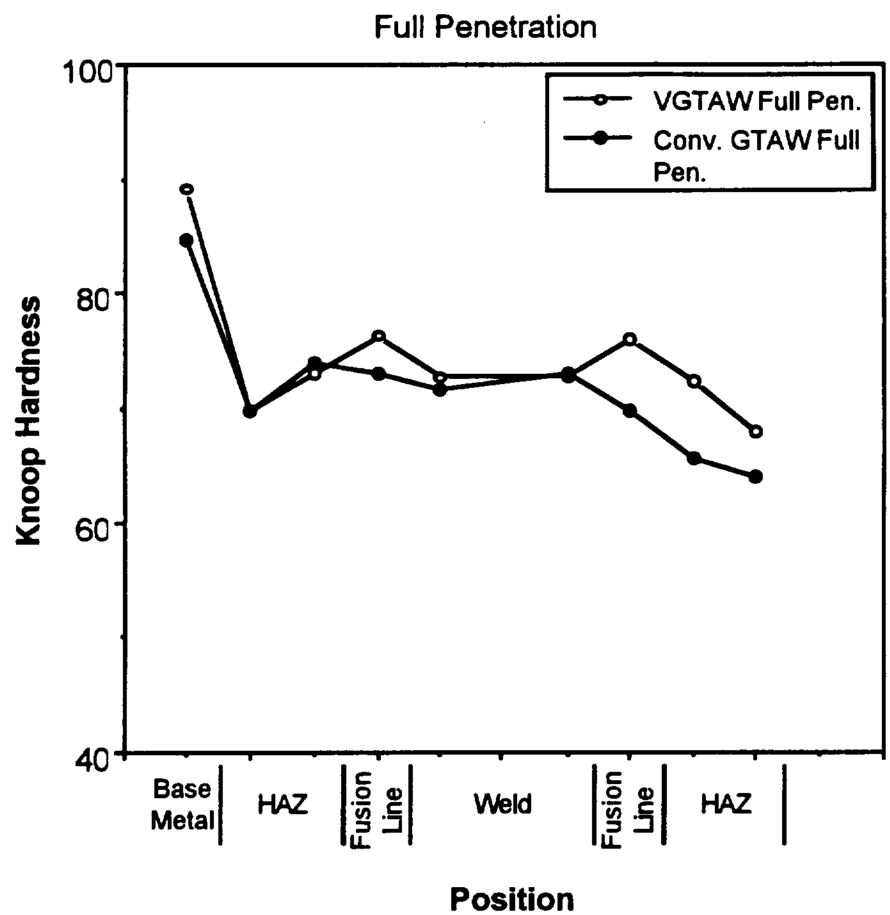


Figure 6. Hardness of VGATW and Conventional Welds on Full Penetration Welds in NARloy Z.

The conventional GTAW was found to have a larger heat affected zone, indicated by recrystallization of the fine-grained, rolled NARloy-Z. This was likely due to the higher heat input of the conventional GTAW. The affect of heat input is very evident by comparing the shallow penetration conventional GTA and vacuum GTA welds. The material below the conventional GTA weld was recrystallized, while that below the vacuum GTA weld exhibits very little recrystallization.

Based on visual observations, the VGTAW process exhibited better wetting of the weld pool material to the parent material. This was attributed to the absence of the atmospheric contaminants present in a conventional GTAW. The apparent increase in fluidity using the VGTAW process can be affected by weldment surface cleaning prior to placement in the vacuum chamber, filler wire surface preparation and vacuum level during processing. Based on these results and the benefit to the SSME, this material was selected for Phase II study.

Incoloy 903 Overlays

Incoloy 903 weld overlay was selected based on SSME fabrication usage. It is used throughout the SSME as a protective barrier to prevent hydrogen embrittlement in Inconel 718. Incoloy 903 is overlaid on Inconel 718 using GTAW which typically requires several weld passes to achieve a sufficient thickness for a hydrogen barrier. After the Incoloy 903 has been deposited, it is machined to the desired geometry and dye penetrant inspected. The inspection may reveal the presence of microfissures.

The initial Incoloy 903 weld overlay samples were processed using as-received Inconel 718 plate prior to completing all of the vacuum chamber modifications. The welding parameters used to apply the Incoloy 903 are listed in Table 2.

Table 2. Incoloy 903 Weld Overlay Parameters

Gas Flow	Current	Wire Feed	Travel Speed
30 ccm	60 amps	25 ipm, 0.045" dia.	10 ipm

In spite of the less than optimum conditions, no microfissures were observed in the Incoloy 903 weld overlays after penetrant inspection (See Figure 9). On this basis, Incoloy 903 overlay material will be investigated in Phase II, Task 21000, Materials Characterization.

Cast Inconel 718

Conventional inert gas tungsten arc welding is the standard process used to weld Inconel 718 cast material. The problems associated with GTAW on this material are microcracks and porosity in the parent material. These problems are caused by thermal induced stresses and distortion due to the welding process.

Sections of a coarse grain (grain size of approx. 1/16 - 1/8 in.) Inconel 718 casting were obtained to evaluate the performance of VGTAW to weld and repair these castings. This type of material was chosen, as previously stated, because it is considered to be hard to weld or unweldable and is a material used throughout the SSME and other aerospace systems.

Weld samples were prepared with VGTAW and conventional, inert-gas welding. The VGTAW sample as compared to the standard GTAW) revealed an increase in weld bead width and reduced penetration as documented in the Phase I Interim report. This geometry can be modified by increasing or decreasing the gas flow rate. The samples did not show a significant improvement with the limited number of samples. Therefore, this material was not selected for Phase II evaluation.

High-Frequency, Pulsed-Current And Air-Coupled Acoustic GTAW of Aluminum-Lithium

The Al-Li material was selected for evaluation based on weldability problems experienced during the SSME Super Light Weight External Tank Program. In that program the Variable Polarity Plasma Arc Welding, (VPPAW) is used for the initial weld. The weld repair is attempted using the GTAW process. During the weld repair evaluation, the material properties of the weld material and adjacent parent material properties are reduced to an unacceptable level. In that investigation it has been determined that a concentration of small, equiaxed grains present along the fusion zone of the weld and the repeated thermal cycling of the Heat Affected Zone, (HAZ), causes most of the material properties loss.

The use of the VGTAW process did not eliminate the material properties problems in the Al-Li although the weld bead geometry was significantly different from conventional GTAW welds. The weld bead depth of penetration was increased while the weld bead width was reduced. No further effort was spent on this program.

Materials Downselection

The evaluation of the welded materials verified the ability of VGTAW to produce improvements over conventional GTA welds. The evolution of the VGTAW process is ongoing and the downselection was based on weld samples processed using the current configuration. The downselection to two of these materials, Incoloy 903 overlay and NARloy-Z, was based on the results of the initial weld samples.

Conclusions And Recommendations. Phase I

The system modifications completed during Phase I improved the VGTAW system and processing capability. The level of control over the vacuum, motion control and gas flow system in this unit allows sample repeatability and process evaluation. This system has demonstrated the ability to incorporate an electro-mechanical, multiple-axes positioning device into a vacuum/welding environment and operate for extended periods of time.

The initial material weld sample evaluation demonstrated the ability to process a variety of materials using the VGTAW process. This system demonstrated that the VGTAW process can change the post-weld condition of the materials tested.

During the Phase I system modification, it became apparent that the gas flow and gas volume can cause dramatic changes in the welding arc geometry. Changes in arc geometry affect the welding power supply output and the weld bead geometry. During Phase II of this program, the gas management system will require further modifications. These modifications will improve control over the gas flow rate and mixing of gases used in this process.

One of the apparent differences between VGTAW and conventional GTAW is a more efficient energy transfer when using the VGTAW process. This was characterized best during the NARloy-Z weld comparison. The VGTAW weld cross section area was ten times that of the standard GTAW weld using the same welding parameters indicating that, to produce the same size weld bead, the heat input and associated thermal effects could be reduced.

The VGTAW process has a variety of potential advantages over conventional metal joining processes. These include elimination of atmospheric contaminants present during processing and increased weld bead depth of penetration with reduced heat input. These process characteristics are desirable in many metal joining applications and could improve the weldability of currently hard to weld materials.

The VGTAW process has changed the post weld condition of the materials evaluated as compared to conventional GTAW. Post weld changes consisted of improved wetting of the weld pool, reduction of heat induced defects, reduction of environmentally induced defects and increased the depth of penetration of the weld as compared to conventional GTAW.

The initial list of candidate VGTAW samples was screened down to two materials; Incoloy 903 overlays and NARloy-Z. The development of the VGTAW process is ongoing and the downselection was based on weld samples processed using the current configuration. The downselection to two of these materials was based on the results of the initial weld samples.

PHASE II. VGTAW DEMONSTRATION

Introduction

The objective of Phase II was to demonstrate the ability of the VGTAW process to produce sound, welds in aerospace-grade hardware in difficult-to-weld materials. Specifically, using the materials downselected Phase I, Incoloy 903 and NARloy Z, perform characterization on VGTAW specimens and then fabricate welds on hardware. Finally, prepare an implementation plan to define how to successfully introduce this technology into a manufacturing environment. The scope of this effort was expanded to include the fabrication of coatings for oxygen compatibility.

The information developed in Phase II was used to determine if the VGTAW process is a practical choice for implementation to solve an existing welding problem. The system modifications made during the Phase I were tested and demonstrated during Phase II of this program, Task 22000, Hardware Demonstration.

Procedures and Results

Incoloy 903 Overlay

A series of Incoloy 903 overlay welds were made using the VGTAW process. The wire feed system and manipulator were mounted to the torch assembly. The torch remained fixed in the chamber and the weld samples were manipulated in 3 axes, "X,Y and Z" below the torch. The initial welds for this demonstration were made while implementing the new wirefeed manipulator. During this implementation several weld samples were processed with interrupted wire feed and reduced wire feed rates. These weld samples demonstrated the VGTAW process could produce microfissures when wire feed rates were reduced while the other weld parameters remained the same.
Table 3 lists the welding parameters used.

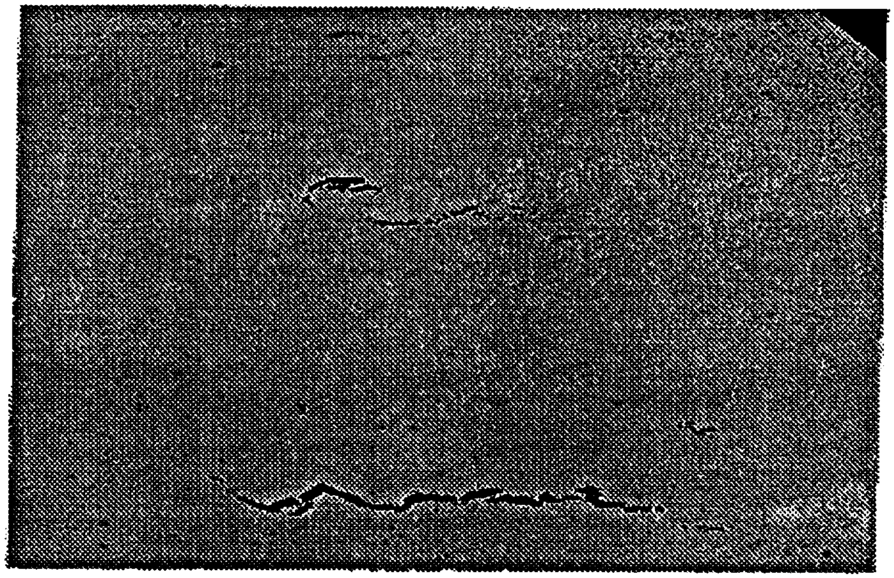
Table 3. Incoloy 903 VGTAW Parameters

Condition	Vacuum Level	Ar Gas Flow	Amps	Travel Speed	Wire Speed
Vacuum	2 millitorr	10 ccm	75	8 in./min.	0 to 10 ipm
Vacuum	2 millitorr	10 ccm	75	8 in./min.	20 ipm
Vacuum	2 millitorr	10 ccm	75	8 in./min.	30 ipm
Vacuum	2 millitorr	10 ccm	75	8 in./min.	40 ipm

The samples in Figures 7-10 show the change in the microfissures as a function of the wire feed rate.

The VGTAW samples in Figure 7 were processed using 0 to 10 ipm of wirefeed. The cross sections of these weld samples showed microfissures are present along the entire length of the overlay. The VGTAW samples in Figure 8 were processed using 20 ipm of wirefeed. The cross sections of these weld samples showed a reduced number of microfissures, but the microfissures are present along the entire length of the overlay. The VGTAW samples in Figure 9 were processed using 30 ipm of wirefeed. The cross sections of these weld samples showed a reduced number of microfissures and areas with no microfissures present. The VGTAW samples in Figure 10 were processed using 40 ipm of wirefeed. The cross section of these weld samples show no microfissures present.

Figure 7. VGTAW of Incoloy 903 with Wirefeed Rate of 10 ipm. Note Microfissures in Heat Affected Zone. Mag. 50X.



V6TA - 1 - 1 25X

Figure 8. VGTAW of Incoloy 903 with Wirefeed Rate of 20 ipm. Note Microfissures in Heat Affected Zone. Mag 25X.

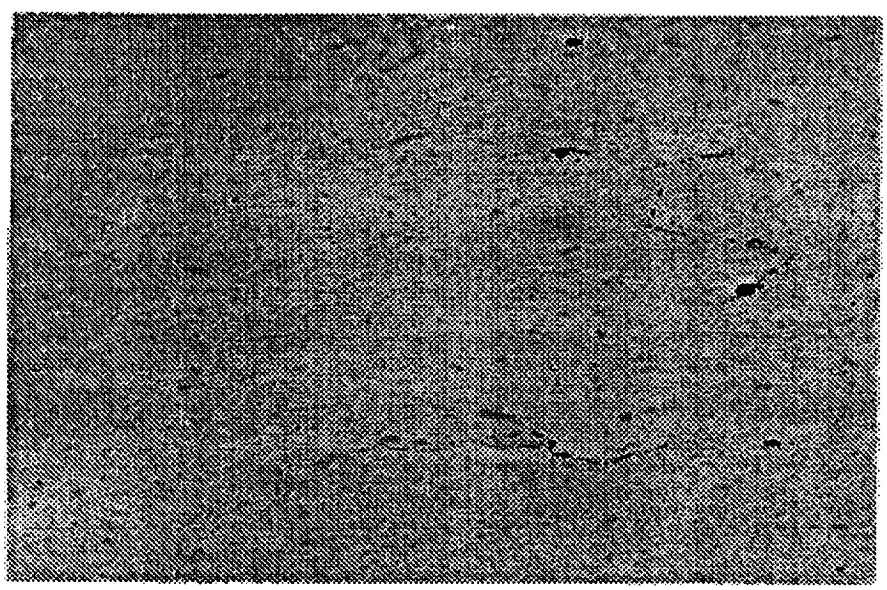


Figure 9. VGTAW of Incoloy 903 with Wirefeed Rate of 30 ipm. Note Number of Microfissures in Heat Affected Zone Have Significantly Decreased. Mag 50X.

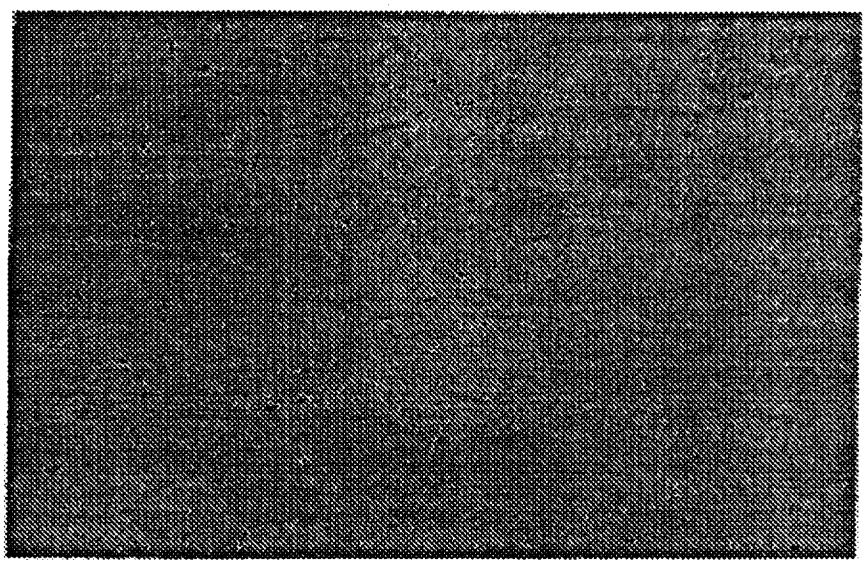


Figure 10. VGTAW of Incoloy 903 with Wirefeed Rate of 40 ipm. Note Microfissures in Heat Affected Zone Have Been Eliminated. Mag 50X.

The other welding variables such as current, travel speed, welding torch position and gas flow also influence the weldability of this material. To further improve the VGTAW process for this application an in-depth study of the effect of these variables is required.

<u>NARLoy-Z VGTAW Samples:</u>

The weld samples used in Phase I were wrought plate. The NARLoy-Z samples used for the Phase II were scrap Space Shuttle Main Engine, Main Combustion Chamber segments. Number 1 and 2 of the four welds processed were on a 2"x2" square segment. These two samples overheated because of start up sequencing due to lack of programmability of the system. Weld samples number 3 and 4 were made on a 6"x10" piece of the throat section of the Space Shuttle Main Engine, Main Combustion Chamber. Weld samples were unexceptable due to drop through into the channel area. These samples were processed using the parameters listed in Table 4.

Table 4. **NARLoy-Z VGTAW Parameters**

Condition	Vacuum Level	Ar Gas Flow	Amps	Travel Speed	Wire Speed
Vacuum	2 millitorr	10 ccm	60	8 in./min.	30 ipm
Vacuum	2 millitorr	20 ccm	60	8 in./min.	30 ipm
Vacuum	3 millitorr	30 ccm	60	8 in./min.	30 ipm
Vacuum	4 millitorr	40 ccm	60	8 in./min.	30 ipm

There were no acceptable weld samples made, using wire feed, on the MCC segments in the channel area. The problems encountered were mainly due to the inability to sequence system variables. The start up sequence is critical for this application. The sequencing of the arc on, travel start and the wire feed start were not programmable with the existing VGTAW system. In an effort to overcome the effects of this problem "arc starting" blocks were used. These blocks of copper were clamped to the MCC segment and used to initiate the arc prior to travel start. This reduced the time the part was exposed to the arc before welding. Using this method the initial section of the weld could be made. The manual current and wirefeed control did not allow the critical adjustments to be made to continue.

The system up grades required to successfully make these welds include programmable sequencing of all of the weld variables and motion devices integrated into one controller. These changes along with an improved gas management system would allow the control to minimize the weld heat input to the channel area of the MCC.

Technical Implementation Plan

As part of the original program plan, an implementation plan was to be prepared to show a path for integrating this technology into manufacturing. The program did not mature the technology as much as had been planned; however, because of the high potential to eliminate microfissuring in Incoloy 903, Rocketdyne plans to work on the development of VGTAW under a company sponsored program.

Materials Characterization of Oxygen Compatible Coatings.

The original program scope was modified to include an effort to fabricate NiCoCrAlY coatings for oxygen compatibility evaluation. Specimens were fabricated by vacuum plasma spray for promoted combustion, particle impact and frictional heating tests and delivered to NASA-MSFC.

DISCUSSION

The VGTAW process is made possible by controlling the environment in the arc region, between the tip of the hollow cathode and the workpiece, with precise adjustments. The introduction of the gas or mixture of gases into this region during arc initiation and arc run is critical to the process. The vacuum level prior to introduction of the gas is 3 $x10^{-3}$ torr. The gas flow required during arc initiation is 75 - 100 ccm. During this period, the pumping system must maintain a vacuum level of 9 $x10^{-2}$ torr. Once the arc is initiated, the gas flow is reduced to 10 - 20 ccm. The gas flow during the arc run period is critical and controls a variety of process parameters.

If the gas flow is reduced from 20 ccm to 10 ccm and the weld current is 80 amps with an arc length of 0.25", the arc geometry changes to a smaller diameter and a more cylindrical shape. This constricted arc appears to reduce the arc spot at the work piece surface, thus reducing the area of energy transfer. This could be the reason for the increase in weld penetration depth to weld bead width over standard GTAW. Gas flow reduction also causes the arc voltage to increase. When the gas flow is reduced, the hollow electrode life is reduced and the erosion to the inside diameter and outside diameter is increased. These effects could be caused by the a reduction in the arc emission area on the inside surface of the hollow electrode and increased heating of a local area or the reduction of the cooling material, the gas, over the inside surface. If the gas flow is increased to 40 ccm using these parameters, the arc voltage is reduced and the arc column becomes more conical shaped. This increase in gas flow also reduces the weld bead penetration and increases the weld bead width.

The system pumping capacity, gas flow regulation into the chamber and electrode geometry are critical to this process. The full extent of their influence is not fully understood yet.

The VGTAW process as expected has changed the post weld condition of the materials evaluated as compared to conventional GTAW. These post weld changes consisted of improved wetting of the weld pool, reduction of heat induced defects, reduction of environmentally induced defects and the ability to increased the depth of penetration of the weld as compared to conventional GTAW.

The change in arc geometry associated with the gas flow has been investigated during Phase II of this program. The factors involved are welding current, vacuum pressure and arc gap as shown in Table 5.

Table 5. ARC GEOMETRY - Weld Parameters

Condition	Vacuum Level	Ar Gas Flow	Amps	Weld Bead Geometry	Weld Bead Geometry
Vacuum	1 millitorr	10 ccm	60	Cylindrical	Width 0.25" Depth 0.25"
Vacuum	2 millitorr	20 ccm	60	Cylindrical	Width 0.28" Depth 0.24".
Vacuum	3 millitorr	30 ccm	60	Conical	Width 0.34" Depth 0.12"
Vacuum	3 millitorr	40 ccm	60	Conical	Width 0.35" Depth 0.11"

The change in weld bead geometry has been noted with micrographs of the welded samples. These weld samples demonstrate that the cylindrical arc column has a reduced arc transfer point at the workpiece and increases the weld penetration while reducing the weld bead width. Because of the limited pumping capacity of the system, the effect of increased gas flow relative to vacuum pressure could not be investigated.

CONCLUSIONS

The system modifications completed during Phase I of this program have improved the VGTAW system and processing capability. The level of control over the vacuum level, motion control and gas flow system in this unit allow sample repeatability but limited the evaluation of all potential applications.

The initial material weld sample evaluation has demonstrated the ability to process a variety of materials using the VGTAW process. This system has demonstrated that the VGTAW process does change the post weld condition of the materials tested.

During the Task 22000 of this program NARLoy-Z and Incoloy 903 overlay material were evaluated. The VGTAW system limitations, in part, eliminated the NARLoy-Z weld repair for the SSME MCC as a candidate application. During the initial material downselect NARLoy-Z was selected as a candidate material based on results of welds made on wrought NARLoy-Z in a plate form. This demonstrator piece did not have the complex shape or the cooling channel geometry to represent the MCC hot wall segment. These two factors combined with the VGTAW system limitations made it impossible to produce an acceptable sample.

The VGTAW process has demonstrated the ability to eliminate microfissures from the weldment and applied material. The weldment material was solution annealed Inconel 718 and the weld overlay material was Incoloy 903. The samples focused on the effect of wire feed rates and the presence of microfissures. When samples were processed with minimum or no wire, there were microfissures present. When the wire feed was increased fewer microfissures were present. When the wirefeed was increased to a nominal rate the microfissures were not present. The other welding variables such as current, travel speed, welding torch position and gas flow would also influence the weldability of this material. To further improve the VGTAW process for this application an in-depth study of the effect of these variables is required.

As a result of the effort conducted under this program, Rocketdyne will continue the development under a company sponsored program. A plan has been prepared and will be implemented.

14. SUBJECT TERMS

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A two-year program investigated vacuum gas tungsten arc welding (VGTAW) as a method to modify or improve the weldability of normally difficult-to weld materials. After a vacuum chamber and GTAW power supply were modified, several difficult-to-weld materials were studied and key parameters developed. Finally, Incolog 903 weld overlays were produced without microfissures.

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