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THE POTENTIAL OF A G.A.S. - CAN

WITH

PAYLOAD G-169

ROCKWELL INTERNATIONAL CORPORATION / CAL POLY SPACE SYSTEMS

SPACE WELDING PROJECT

WRITTEN AND PRESENTED AT
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ABSTRACT

As we venture into space it becomes necessary to produce, expand and repair structures for our housing, research and manufacturing. The microgravity-vacuum of space challenges us to use construction options which are commonplace on Earth. Cal Poly Space Systems and Rockwell International Corporation have jointly taken on the challenge of construction in space using the option of welding. However, the conquering of such a challenge through a joint cooperation between students and industry is made possible by NASA's Get Away Special Small Self-Contained Payloads Program.

The potential of a Get Away Special (GAS) canister is proven through the development of a dream into a reality. The dream is space based construction, expansion and emergency repair via welding. And the reality is presented in this paper.

BACKGROUND

Why weld in space ?

In recent decades, welding has become a dominant process for building metal structures on earth. The rapid and continuing growth of welding applications is due to the inherent advantages of this joining method over mechanical and adhesive techniques. Such advantages as high joint strength, reduced mass, improved hermetic sealing, increased flexibility in design of structural joints, quicker application to unique scenarios, and consequently reduced overall cost are dramatic on earth but become even more attractive in space.

The high cost of shipping building materials into Earth's orbit is a difficult and limiting burden. Any potential mass reductions have to be utilized; from design through fabrication. Welding allows for mass reductions by eliminating the need for oversized mechanical joints. The extra components and increased gage of parent members at the mechanical joint are necessary to provide means of joining with acceptable strength [1]. Alternatively, for welded joints the most required could be a minimal amount of filler metal for bridging gaps during fit-up problems.

Limited dexterity available to the astronaut in extra-vehicular activity (EVA) requires expensive specialized mechanical connectors. Even though the development of an EVA welding system would not be cheap for the astronaut with the same limited dexterity, in the long run the overall cost of numerous and diverse mechanical connectors would far outweigh the cost of a versatile space welding system.

Meteors and space debris pose a growing collision hazard as we advance to inhabit space. When setting this hazard in a vacuum, the repair of damaged structures containing human life becomes significantly more critical than in the terrestrial environment. Repair time is of the essence. Hence, the versatility of a joining process must be maximized. Welding is far more versatile than any other metal repair method. Welding requires relative minor surface preparation of the component to be repaired. While mechanical repair could require machining preparation and corresponding tools, specialized fasteners, hermetically sealing adhesives, and consequently a great deal of unaffordable time.

In conclusion, welding is a primary candidate process for construction, expansion and emergency repair of space based structures.

Which welding method should be used ?

Any welding process developed for use in space should be amenable to both manual and automatic use and have the extra versatility to work inside pressurized life supported quarters as well as in the outside vacuum. The process must have reasonable productivity; it must be efficient in utilization of energy; it must work on a variety of materials (i.e. light metals, refractory metals and composites); it should provide capability in construction, expansion and repair; it should be forgiving of joint mismatch or fit-up problems; and it should use a minimum weight of consumable materials [1]. However, to choose one single welding technique which maximizes each of the so many requirements for a space welding process is impossible. Thus, it is necessary to start with the method which possesses the best overall combination of properties.

Gas Tungsten Arc Welding (GTAW), better known as Tungsten Inert Gas (TIG), has been selected as the welding process to best fulfill the requirements of a space welding system. When GTAW is compared with its best adversary, electron beam welding, GTAW proves to have a superior potential in manual operations and adaptability to imprecise fit-up problems with structural members [1]. Other draw backs of electron beam welding include the need to shield the astronaut from X-ray radiation produced during this joining process, and the need for a vacuum which is impractical for welding inside life supported pressurized quarters. Also, the energy requirements of a GTAW system can be easily met by a rechargable and relatively small battery package. Such versatility would be crucial in repair at locations remote from a power source or during power-down emergency situations on the space station.

However, the significant draw back for GTAW is the requirement for a medium which would transfer the welding arc from the tungsten electrode to the work-piece. Such a medium is supplied on earth by an inert gas (argon or helium or both--also used to prevent the solidifying weld from reacting with oxygen and nitrogen). The inert gas is ionized into a plasma which transfers the welding arc. In space the conventional introduction of an inert gas for plasma formation would prove useless because of the hard vacuum environment. But, a proprietary modification to the terrestrial GTAW process, developed and demonstrated by the Rocketdyne Division of Rockwell International, overcomes the vacuum limitation [2]. Therefore, the fundamental drawback for space based GTAW is eliminated.

In conclusion, the advantages of GTAW outweigh the benefits of its adversary welding techniques; even those of electron beam welding.

What about microgravity effects ?

The environment of space imposes on GTAW an unknown effect due to microgravity. In order to extend the inherent advantages of earth based welding out to space, it is important to compare the properties of a terrestrial welded joint with those of its space counterpart.

Concerning the solidification of a molten weld pool, theory suggests that the absence of gravity eliminates buoyancy driven convection, isothermal buoyancy, sedimentation and metallostatic pressures [3]. For example, the lack of buoyancy driven convection may entrap bubbles formed at the solidification front [3,4]. This would introduce porosity; therefore, increasing the affinity to corrosion and reducing joint strength. On the other hand, the elimination of buoyancy driven convection may also eliminate micro- and macro-segregation thus promoting a more homogeneously solidified material and improving joint characteristics. Weld seam geometry is another interesting example of controversy. One theory suggests that, with the absence of metallostatic forces, surface tension will cause the liquid metal pool to assume a near spherical shape which would minimize surface energy. However, another view point stresses that a liquid medium in microgravity would demonstrate higher affinity towards its solid parent medium than it would in a 1-g environment; resulting in a thinning of the weld pool and solidifying seam [4]. Obviously, experimentation is required to settle these controversies and many others.

Even though the United States, USSR and West Germany have experimented with microgravity welding, no substantial data exists about GTAW [3,5]. In addition, data from the welding techniques already performed in microgravity vary with the processes, joints and materials used -- no definite common trends exist. Some samples show porosity while others don't; some samples reveal larger weld zones while others don't; some samples suggest a more uniform grain structure throughout the heat affected zone while others don't; and some samples show greater reinforcement of welded seams while others don't [3]. Unfortunately, uncertainty exists with the available experimental data relating the effects of microgravity to macro- and microstructural properties of welded joints.

In summary, more factual data about welding in microgravity is needed as a first step in qualifying GTAW as a metal joining process for space based operations. The vacuum of space can be simulated very closely on earth; and indeed Rockwell International has already demonstrated a method for vacuum GTAW. But, microgravity is harder to come by. Hence, the Rockwell International / Cal Poly Space Systems' G-169 is meant to reveal the effects of microgravity on the properties of the solidified Gas Tungsten Arc (GTA) welded joint.

G-169

Objective :

The objective of G-169 is to allow comparison of a space GTA welded joint to a terrestrial GTA welded joint with all welding parameters held constant except for gravitational forces. Upon retrieval of G-169 from its mission, the space welded specimen will be compared to its terrestrial counterpart via metallographic examinations such as macro- and microphotography, microhardness, tensile, radiography, and scanning electron microscopy.

The most likely and preliminary candidate for space based GTAW application would be the Space Station's power system (contracted to Rockwell International's Rocketdyne Division) [5]. Rocketdyne's Space Station power system design includes a considerable amount of stainless steel plumbing for flowing heat transfer fluids. At present, mechanical connectors which are unavoidably bulky, heavy and expensive are used at the plumbing joints. On the other hand, the use of GTA welded joints, which exhibit superb low profile beads, would be ideal for plumbing. Hence, in order to maintain a direct application for the specimen to be welded, a bead-on-plate-weld around the perimeter of a 2.00 inch diameter Stainless Steel 316-L pipe section will be performed; to simulate a butt-joint (an actual butt-joint would require two adjacent pieces of pipe which may vibrate and separate during shuttle launch).

Concept : (see figure)

The basic components of G-169 consist of a controller, battery-pack, power inverter, welding computer, welding head, and an inert gas pressure vessel. The controller manipulates and safeguards operations of the payload components. The rechargable battery-pack supplies power to the entire payload via the controller. The power inverter converts the DC power-output of the battery-pack to a compatible AC power-input for the welder's operation.

The welding computer regulates power to, and operations of the welding head and inert gas purge. The welding head, housing a rotating tungsten electrode, welds along the outside perimeter of the pipe specimen. And last, the inert gas pressure vessel floods the welding area with argon in order to imitate the gas's presence in earth like GTAW. Prior to launch, the G-169 payload is purged in a GAS canister with dry nitrogen gas at one atmosphere of pressure simulating the terrestrial environment (oxygen is eliminated to safeguard against a fire hazard).

Operational Scenario :

The sequence of operations on G-169 is regulated by a cooperation of the controller and the welding computer. Placing switch (A) of the Astronaut Payload Controller (APC) in the "HOT" position initiates start-up of G-169's (internal) controller. The controller initiates a 30 minute time delay to permit cessation of astronaut activity (into a sleep period); in order to achieve as low induced accelerations as possible on the orbiter. Following the delay, power is applied to the welding computer through the power inverter. The computer initiates an additional 7 minute time delay to permit some of its sensitive circuitry to warm up to a safe operating temperature. Following this second time delay welding is performed. The welding procedure involves 30 and 20 second periods of argon gas-flooding of the weld zone, prior and after (respectively) actual welding takes place. The actual welding (arc transfer) takes approximately 2 minutes, during which argon gas-flooding continues and the tungsten electrode rotates around the stationary pipe specimen in a programmed manner. Upon completion of the welding procedure the welding computer signals the controller to cut-off all payload power immediately. The duration for the entire experiment, including time delays, is 45 minutes.

Spin-Offs for GAS Users :

Following the Challenger tragedy and the consequent halt of Space Shuttle flights, Rockwell International convinced NASA to provide other means of microgravity simulation for G-169.

NASA Lewis Research Center, specializing in microgravity research, is sponsoring G-169 with at least four free flights aboard a special Learjet aircraft. A microgravity environment, varying from 0.001 to 0.01 g's, is attainable for approximately 20 seconds by flying the aircraft through a Keplerian trajectory. The maneuver is entered from a slight dive requiring a 2- to 2.5-g pullup just prior to nulling the accelerations in the three primary axes and it is terminated with a similar pullup to level flight attitude. During the maneuver all personnel, including civilian experimenters, are constrained in seats. In order to attain minimal induced accelerations a maximum of six trajectories can be flown before landing and relubrication of aircraft controls.

In conjunction with G-169, NASA Lewis has acquired a GAS-can and developed an interface between the canister and the jet. Even though a Learjet microgravity simulation does not provide ideal experimental conditions for G-169 (only 20 seconds of microgravity), it will allow an interesting spectrum of gravitational forces between 0.001- and 2.5-g loads, a variety of specimens, and a check of payload performance.

G-169 will set the path for other GAS experiments to be flown aboard the Learjet. In contrast with the Space Shuttle, Learjet-benefits for the GAS user may include reduced flight cost, lowered safety requirements, personal experiment operation and the ability to correct minor experimental failures if they should arise. In addition, Learjet flights may reduce the backlog of shuttle GAS payloads and expedite return of experimental results.

OTHER DEVELOPMENTS AND FUTURE PROSPECTS

In response to NASA's 1987 competition for Out-Reach in Space Technology (ORST) grants, a joint entry was submitted by Rockwell's Rocketdyne Division and Cal Poly's Aero Department. The entry was a proposal for the definition and design of a space flight experiment to evaluate the feasibility of performing manual welding tasks in an EVA environment. Rockwell and Cal Poly used their work on G-169 and vacuum GTAW to establish a leading edge for their entry. The ORST competition, requiring the cooperation of industry and university, awarded over $120,000 to the Rockwell-Cal Poly proposal for a 12 month design contract. Upon completion of the EVA welding experiment design, Rockwell and Cal Poly plan to reenter the ORST competition and submit a follow-on proposal for a substantial grant to develop the experiment for actual shuttle flight.

UNIVERSITY-INDUSTRY-GOVERNMENT TRIANGLE

Get Away Special Payload #169, is a manifestation of a working relationship between the academic institution, the aerospace industry, and the government; where all partners cooperate and benefit in their own ways.

In 1983 a group of engineering students, attending the California Polytechnic State University (Cal Poly) in San Luis Obispo, decided to weld in space. The only realistic path, both economically and technically, was through NASA's unique Get Away Special program. After almost two years of futile soliciting for donations and equipment, the student group established contact with a generous aerospace company which saw potential in the "space welding" dream. The company was the Science Center of Rockwell International Corporation. Rockwell agreed to finance a five cubic foot GAS canister and all related project expenses; including some student travel to the annual Get Away Special Symposium. Rockwell also extended their resources, expertise and a project manager. The payload manager was appointed from the Cal Poly student group and the project advisor was appointed from the university's faculty. The student group was responsible for the design, purchase, fabrication, integration and testing of components for the G-169 payload as well as interfacing the project with NASA. Semiannual progress reviews and regular communication were maintained between the students and staff (engineers, scientists, etc.) from Rockwell International and NASA. An ideal cooperative working relationship was established between university, industry, and government.

University students apply and sharpen skills and knowledge which they acquire in the class room and laboratory; at the same time, they learn a whole new "ball-game" -- the development of a space rated system from technical and bureaucratic perspectives. Industry's "citizenship" reputation improves with their financial and technical involvement. And with the addition of governmental IR&D support a small student side project slowly, but surely, opens doors into serious aerospace applications and potential contracts. Finally, NASA acquires fame for its successful GAS program, and possibly new tools for space exploration.

CONCLUSION

Cal Poly's motto is LEARN BY DOING, and the Get Away Special Program makes it possible by completing the university-industry-government triangle. Both the economical and technical feasibility of a GAS payload allow an aerospace company (like Rockwell International) to extend the helping hand which a student run, learn-by-doing, space project needs. A student group needs a trusting, patient and generous hand which can pull strings and show the way when needed. The Get Away Special Team at NASA Goddard also supplies educational safety reviews and fascinating symposiums as well as granting students the experience and honor of presenting a technical paper to the prestigious aerospace community.

The Get Away Special is a credit to our nation. Programs such as GAS make America special. On behalf of the aerospace students in the United States, I salute the GAS TEAM. Thank you.

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REFERENCES

[1] Eagar, T.W., Professor, Materials Processing Center, Cambridge, MA, MIT, "Prospectus for Development of a Rational Welding Technology for Fabrication in Space", presented to Rockwell International's Rocketdyne Division, 1987.

[2] Gordon, S., "Development of GTAW Welding Process for Welding in a Vacuum", Internal Rockwell International Rocketdyne Division Report, 1987.

[3] Hoffmeister, H. and Rudiger, J., Laboratorium fur Werkstoffkunde und Schweibtechnik der Hochschule der Bundeswehr Hamburg, "An Investigation of the Current State of Research into the Influence of Gravity on the Joining of Metals by Means of Liquid Phases", 1981.

[4] Blake, A. W., former G-169 Payload Manager "Gas Tungsten Arc Welding in a Microgravity Environment Work Done on GAS Payload G-169", 1986 Get Away Special Experiments Symposium, NASA Conference Publication 2438.

[5] Muir, A. H. Jr., "Materials Processing in Space -- Welding in Microgravity", Internal Rockwell International Science Center Report, 1986.

CONCEPT OF G-169