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Paper Session II-C - Space Welding: On the Agenda

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SPACE WELDING: ON THE AGENDA

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ABSTRACT

In 1997 the United States and the Ukrainian Space Agency are scheduled to cooperate in the International Space Welding Experiment (ISWE), a flight demonstration on the U.S. Space Shuttle of the space welding tool developed at the E.O. Paton Electric Welding Institute. ISWE will demonstrate the feasibility of repairing a space structure by welding as well as providing more data on space welded joints. It will move welding in space closer to the same dominant position that welding occupies today in the terrestrial fabrication of launch vehicles and their payloads.

The development of space welding will be a complex task, as exemplified by the long history of development in the Ukraine. Besides the welding process itself it is necessary to address component assembly, weld joint configuration and fit up, and post weld inspection and verification in any contemplated welding operation. But the reward, a basic and versatile "universal" tool for assembly, construction, and maintenance of hardware in space, is not trivial either.

As we move into the twenty-first century America's Space Program, pushing forward in its "better, faster, cheaper" mode, is embracing new ways of doing business to achieve its goals. The cooperation between the United States and the Ukrainian Space Agency represents such a new way of doing business in the interests of "better, faster, cheaper" progress into space.

BACKGROUND

The development of space is progressing through the cooperation of countries working together. World economics makes this necessary, as it is too expensive for any one country to do it alone. Funding for research and development will not allow for the duplication of efforts. The International Space Station Alpha (ISSA) is the first example of world cooperation to achieve mastery of space. Continued exploration of the solar system, and the universe beyond, will follow the same joint approach.

The architectural solutions used by the designers of space structures in the future can be economically justified by the guaranteed service of these structures over long terms. This will require the development of technologies capable of minimizing the cost of space structures. The world's experience in the service of different kinds of critical structures operating in the extreme environment of space shows that the application of permanent joining in situ for assembly, repair, and maintenance can provide long service life of these structures which can successfully compete with the alternative of mechanical joining. Therefore, if the designers of space structures possess the technologies and tools needed for making permanent joints in space, there is no doubt that such joints would be preferable.

The United States first investigated the feasibility of welding in space in 1973 on Skylab, when electron beam welding was demonstrated as part of the M512 experiment (figure 1). The Marshall Space Flight Center (MSFC) of the National Aeronautics and Space

Administration (NASA) managed the experiment which showed, through bead on plate welds on 2219 aluminum, pure tantalum, and 304 stainless steel, that the molten weld pool was not affected by the lack of gravity, and that surface tension forces instead dominate the molten pool.[1]

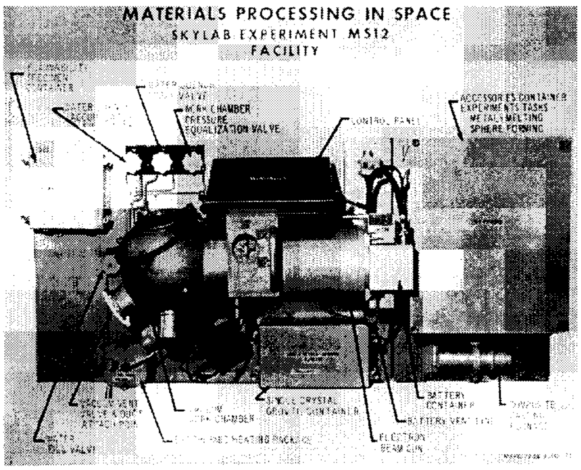

Figure 1. Skylab Experiment M512

NASA abandoned further development of space welding until 1989 when four small study contracts were awarded to develop Space Shuttle flight welding experiments. These proposed experiments were not pursued. Vacuum arc welding development has continued through the Small Business Innovative Research (SBIR) program. In 1994, the International Space Welding Experiment was selected by the Flight Demonstration program with launch currently planned for 1997.

In the former Soviet Union space program, the development of space welding also began in the 1960's. All research was carried out at the E.O. Paton Electric Welding Institute (PWI) in Kiev, Ukraine. During the early years development was concentrated on the design of small-sized equipment for investigating a wide range of technologies for the permanent joining of metals used in the aerospace industry. Many methods of welding and brazing were studied in extreme conditions simulating the space environment, such as: vacuum, high and low temperatures, and weightlessness. These searches enabled the scientists of PWI to select the electron beam, plasma and consumable electrode welding processes. The first welding experiment made 25 years ago on October 16, 1969 by cosmonauts G. Shonin and V. Kubasov with the "Vulcan" apparatus (figure 2) convinced scientists and specialists of the most promising capability of electron beam technology. It satisfied the requirements of high and clean vacuum, high energy concentration and efficiency, and easy control, as though designed for space.[2]

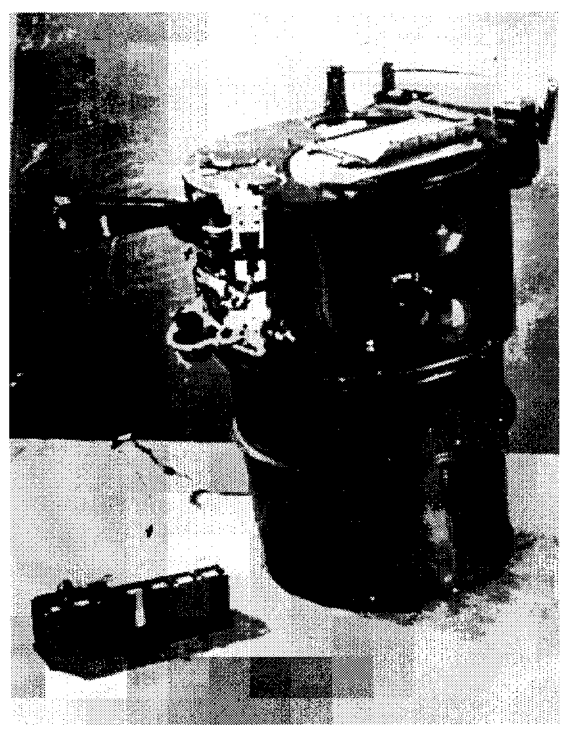

Figure 2. Vulcan Space Welding Equipment

During recent years, a range of electron beam tools has been developed at PWI, operating in the automatic and semiautomatic modes which enable the deposition of different protective and optical coatings, the growing of single crystals and zone melting of metals, welding, cutting, and brazing of structural elements of aerospace objects.

Originally, the PWI scientists had doubts of the possibility of using electron beam as a hand-held tool. These doubts concerned both the safety of such a tool due to high voltage, secondary x-ray radiation, high energy concentration in the beam, the potential to burn the spacesuit from random beam exposure, and the capability of a human being to manually control the beam. On Earth there was no need for a manual electron beam welding tool, and the highly skilled specialists in the field of electron beam technologies did not believe in the capability of a man to control manually such a precise process. Not only Ukrainian scientists had doubts, but published literature in the late 1960's documented the same concerns of American specialists. Experiments with an operating model of an electron beam hand tool (VHT) (figure 3), made in a special vacuum chamber 20 years ago at the Paton Institute not only settled this doubt, but also demonstrated the capabilities of this technological process.

A special facility with a stringent requirement of safety was designed for the conductance of these experiments (figure 4). The facility consisted of a vacuum chamber, equipped with a self-contained high-vacuum pumping unit, a semi-spacesuit built into the chamber wall permitting the operator to manipulate the tool and materials being treated in the chamber. The high vacuum chamber was located inside a larger vacuum chamber, in which the operating pressure admissible for a spacesuit, i.e. 0.4 ATM was maintained and a safety observer was located.

Figure 3. First Operating Electron Beam Hand Tool

This scheme enabled the operator to quickly exit the semi-spacesuit in case of danger.

The tests revealed an unexpected ease of hand control for the electron beam and a stability of process, permitting rapid training of cosmonauts and others without experience in welding.

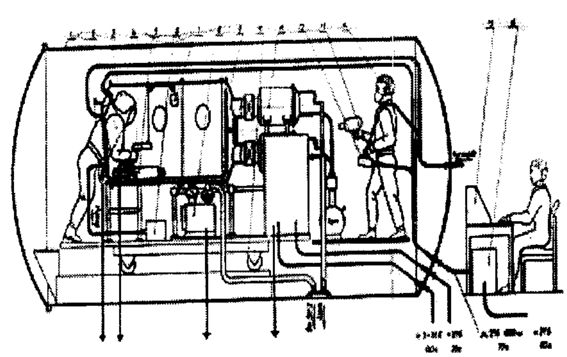

Figure 4. Manual Electron Beam Welding Facility

During the same period specialists at PWI designed and tested in vacuum and micro-gravity models of tools for arc and plasma welding. Because of technical and other difficulties, the decision was made not to develop these technological processes to flight models.

In 1981 PWI began to design the electron beam welding tool of 0.5 kW capacity for assembly and repair applications in space. In 1984 cosmonauts S. Savitskaya and V. Dzhanibekov demonstrated the capabilities of the versatile hand electron beam tool (VHT) during their mission at “Salyut-7” station (figure 5). Numerous experiments on welding, cutting, brazing, and coating on flat samples were performed. Two years later cosmonauts L. Kizim and A. Solovyov continued the work with this tool, carrying out welding, cutting and brazing on mock-ups of three-dimensional structures and connections. All the cosmonaut-welders and their back-up men were trained on earth in a special manned vacuum chamber using the EVA spacesuit “Orlan”.

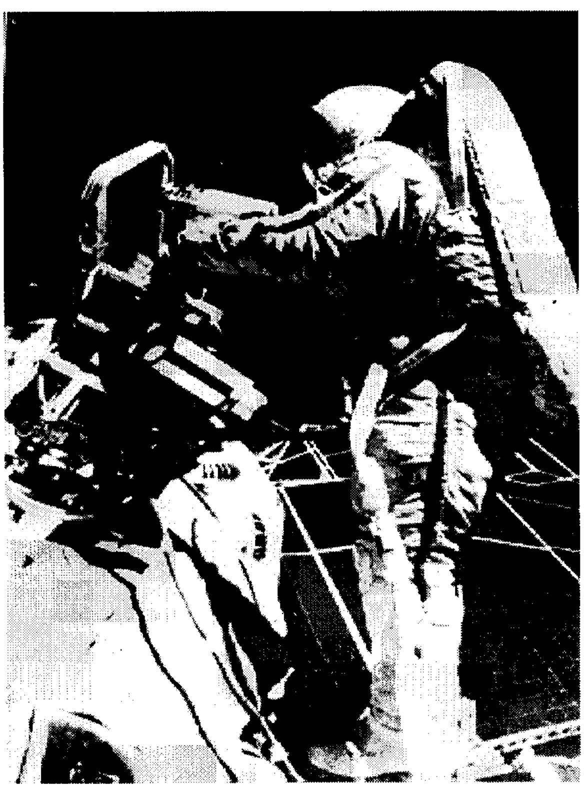

Figure 5. Welding in Space using the Versatile Hand Electron Beam Tool

At present, a 1.0 kW electron beam tool has been designed, with broadened capabilities including a filler wire feeding mechanism. The tool passed all tests required for equipment designed for service on board a space vehicle. The capability of this generation of equipment guarantees success in construction, assembly, and repair works in space.

CURRENT ACTIVITIES

In 1994, the International Space Welding Experiment (ISWE) was selected as a Space Shuttle Flight Demonstration with launch currently scheduled for October 1997. The experiment brings together the skills of the Marshall Space Flight Center, The Paton Welding Institute, Johnson Space Flight Center, Goddard Space Flight Center, McDonnell Douglas Aerospace, and Genesis International. The flight experiment will assess the applicability of the Ukrainian Universal Hand Tool (UHT) to materials and configurations typical of U.S. space design. Scenarios to be investigated include maintenance and repair, surface coating, cutting, and joining. These tests will provide data allowing space systems designers to expand their options for in-space construction and maintenance.[3]

ISWE makes use of hardware provided by both MSFC and PWI (figure 6). The 1.0 kW UHT system has been leased from PWI for the flight demonstration.

The workstation has been designed and manufactured by PWI. NASA is providing 61 flight samples, the sample holding plate, and interface hardware between the Ukrainian components and shuttle elements. The challenge of combining the systems and operating methods from two countries has been successful due to open communication and cooperation between all the parties involved.

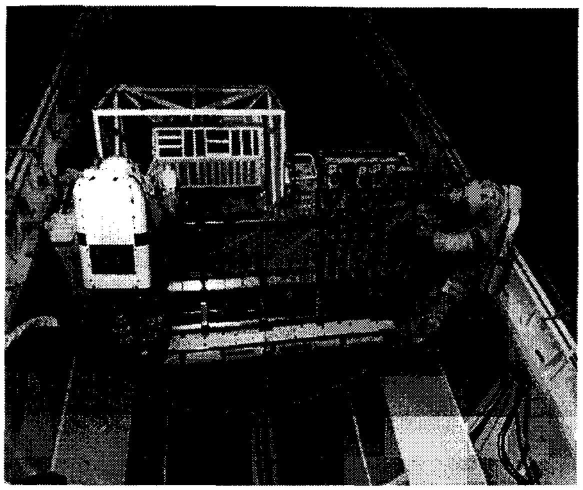

Figure 6. ISWE Development Hardware

Although not baselined as a maintenance and repair operation for space station, welding could be used as a contingency method for maintenance and repair after successful demonstration and development as a viable method.

Therefore, the first objective of ISWE is to evaluate the Universal electron beam system performance as a contingency repair tool for space station unplanned maintenance. One cause of unplanned maintenance is damage caused by micrometeroid or orbital debris. Debris impact could damage the following space station elements:

- modules
- solar array support structures
- booms
- radiator panels
- fluid lines
- external tanks

In many cases it may well not be cost effective or even feasible to simply replace damaged elements and in-place structural repair may be indicated. It is not the intent of this experiment to determine the optimum approach to an ISSA maintenance plan, rather it is to establish the feasibility of using the electron beam welding process in space.

The second objective of ISWE is to evaluate the human interface with the Universal electron beam system in an extravehicular activity (EVA). Two astronauts will conduct a 6 hour EVA to process the ISWE samples.

The third objective of ISWE is to provide samples for the development of a weld properties database.

The applications selected for demonstration of welding repair are module damage due to debris impact and fluid line leaks. Orbital debris impacts to space station modules have been shown to result in through-hole penetrations. Samples have been selected which replicate a section of module isogrid after impact. Plate patches will be welded over the damaged section. Samples have been chosen to replicate both the U.S. and Russian module materials and design. The second potential repair scenario demonstrates plugging a pin hole in stainless steel tubing. Pin holes could develop in highly stressed areas over long periods of loading. The third scenario demonstrates brazing a sleeve onto a stainless steel tube. This repair method could be applied over leaking mechanical joints in tubing systems. Mechanical joints could lose their sealing ability after long periods of loading.

The basic hand tool accommodates welding without filler wire (autogeneous), cutting, and brazing, which will be used most. Three different attachments are available with the basic hand tool. One attachment allows welding with cold filler wire addition. Three hand tools equipped with different filler wire materials will be used on ISWE. Two other hand tool configurations are designed for applying coatings. In one case the coating material is in wire form and in the other the coating material is contained in a crucible. The coating with crucible attachment will also be demonstrated. Samples will be placed in two different orientations, vertical and horizontal with respect to orbiter bay coordinates, for evaluation of welding position. The molten weld pool will not be affected by weld position due to the absence of gravity, but ease of manipulation may be affected by attitude. Forty-eight of the samples are rolled plate to provide mechanical and nondestructive test specimens. The number of samples were selected to provide sufficient weld lengths for statistical comparisons to samples processed on the ground. Differences between ground and space processed weld appearance or mechanical properties will be further analyzed for metallographic characterizations.

Two astronauts will be used to weld the 61 samples, each welding half of the total number of samples. A third astronaut will provide processing feed-back to the two EVA astronauts from the orbiter aft flight deck. The astronauts will receive extensive training to develop proficient welding skills. This includes recognition of a full penetration weld, ability to track the weld joint, and the ability to create a visually acceptable weld. Gas tungsten arc welding (GTAW) will be used to develop basic manual welding skills followed by extensive familiarization with the electron beam process using a portable vacuum chamber. The final training exercise will require a manned vacuum chamber to enable duplication of the flight configuration in an environment adequate for electron beam welding.

It is anticipated that this experiment will provide some data on the suitability of different weld joint configurations for space applications. This experiment will determine the suitability of performing manual welding operations in space, as well as provide preliminary information on the versatility of the electron beam welding process.

FUTURE NEEDS

The International Space Welding Experiment is only one more step in the development process of space welding. In order for welding to be considered viable in space, welding must be demonstrated as capable of satisfying the design requirements of space hardware. The samples to be welded on ISWE will be set-up and assembled on earth prior to launch into space. The astronauts will only demonstrate the welding techniques required for welding simple plates. However, other processing steps are necessary when performing maintenance or construction activities. These include removing damaged components (repair) and assembling components to be joined.

Surface preparation and fit-up of the weld joints will be difficult in the space environment. Postweld quality inspection requirements add to the complexity of the welding operations. The high level of quality required from these operations increases the complexity of these operations in the space environments of vacuum, light-dark orbits, and thermal gradients. Manual operations are restricted by space suits and astronaut safety considerations. Robotic operations must have the flexibility required for widely varied tasks.[4]

New techniques for assembly and inspection of welded structures will need to be developed as space welding matures. The International Space Welding experiment is another step towards the development of space welding as a tool available to future planetary and space habitation endeavors of the world.

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