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Vacuum Compatability of Welded Joints for NSTX-U

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The high vacuum environment of the National Spherical Torus Experiment (NSTX) cannot tolerate a leak rate of greater than 1x10-5 Torr-liters per second or an out-gassing rate of more than 2x10-12 Torr-liters per second per cm². This is maintained with an austenitic 316 stainless steel vacuum vessel. The NSTX Upgrade (NSTX-U) will require large weldments attached to the current vacuum vessel that will become the new vacuum boundary. Due to the lack of superstructure, all loads are passed through the vacuum vessel. This means the welds must carry a substantial load as well as provide vacuum integrity. Distortion of the vessel must also be minimized in order to accommodate precisely-aligned diagnostics as well as to mate to the new second neutral beam. The ideal candidate for these welds is Flux Cored Arc Welding (FCAW). FCAW can deposit a great amount of weld material quickly with minimal heat input. This paper will discuss the vacuum compatibility of FCAW and compare it to other standard welding processes used on NSTX.

I. INTRODUCTION

The design of the upgrade of NSTX includes major modifications to the vacuum vessel. In order for diagnostic views to be maintained around the enlarged center stack, two ports must be replaced. The addition of a second neutral beam at a different tangency radii than the originally designed port allowed for, requires the major modification of two port segments. A large hole will be cut around these two ports and a port cap will be welded in. This cap will move the vacuum vessel wall outboard ~6 inches. The load bearing design of the vacuum vessel requires that these welds be full penetration. Due to the more powerful magnetic fields from the attached coils, the vessel will see increased loads over the stress threshold of the existing metal. In order for the vessel to handle these extra loads, additional reinforcement will be required at strategic areas around the perimeter.

The welding required to perform these modifications must be full penetration in order to carry the loads that are directed through the vessel. Due to the thickness of the plates involved (5/8" to 1.5"), J grove weld preparations were chosen to minimize the amount of weld metal that is needed. This weld prep design is ideal for use on thick plate where minimal heat input and volume of deposition is desirable.

II. METHODOLOGY

The samples tested were made from 316 stainless steel plate. They were water jet cut, wire brushed, and cleaned with acetone before welding. After the appropriate welding process was performed, the samples were cleaned again with acetone. The photographs show the samples in an as tested condition. Notice the silica and discoloration that remains at the toe of the weld. This was left on to give an example of a worst case scenario of welding in situ in a position the will not allow access for thorough cleaning or grinding. Samples were then placed in a RGA chamber and pumped down. The RGA was monitored as the sample was heated up to 450°C and back down. Out gassing rates and times were monitored. The time it took for out gassing to stop was also monitored.

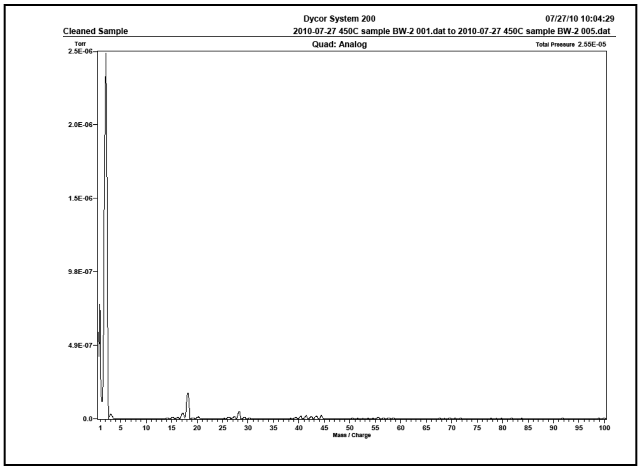

Figure 1. *Background Signal*

III. WELDING PROCESSES

Three different welding processes were performed for these trials, along with a machined stainless steel block, used for a background signal. Both Gas Tungsten Arc Welding with filler and fusion welds were tested. These are the current methods for welding on the NSTX vacuum vessel. Gas Metal Arc Welding was tested as another common welding method for joining stainless steel. Four types of Flux Cored Arc Welding wire from different manufactures were tested.

Gas Tungsten Arc Welding (GTAW) is commonly called TIG welding. This is a manual arc welding process that uses a non-consumable tungsten electrode attached to a constant-current power supply and shielding gas to produce the weld. A filler metal is normally used, though some welds known as fusion welds, do not use filler. GTAW has a low deposition rate and high heat input. It is best suited for small intricate work that requires precise clean welds.

Gas Metal Arc Welding (GMAW) is commonly called MIG welding. This is a semi-automatic arc welding process in which a solid continuous and consumable wire electrode and a shielding gas are fed through a welding gun. A constant voltage, direct current power source is most commonly used with GMAW. There are four primary methods of metal transfer in GMAW. They are globular, short-circuiting, spray, and pulsed-spray, each of which has distinct properties and corresponding advantages and limitations. GMAW has a moderate deposition rate and is best suited for work involving thin base materials. When used on thicker sections there is a high chance of lack of fusion in the root of the weld. In order to avoid this discontinuity it is necessary to run higher currents. However, this leads to higher heat inputs. To avoid the lack of fusion without the higher heat input a pulsed GMAW processed can be utilized. Regulated Metal Deposition (RMD) is a pulsed process that can be employed to perform this. This form of GMAW pulses the voltage and wire feed speed. RMD allows for higher currents and for better fusion with a lower heat input than other wise possible with conventional GMAW.

Flux Cored Arc Welding (FCAW) is a semi-automatic arc welding process that requires a continuously-fed consumable tubular electrode containing a flux and a constant-voltage welding power supply. An externally supplied shielding gas is use on stainless steel. This process is best suited for the joining of thick sections of metal. FCAW is similar to GMAW in that it is a semi-automatic welding process using a filler material as the electrode. The tube contains a flux for cleaning and shielding as well as metallic particles that make up the bulk of the filler material. Since the filler is in particulate form it requires less heat input to reach the melting point in comparison to GMAW. FCAW is also run at greater wire feed speeds allowing for greater deposition rates over a given period of time.

All processes described here have the ability to be performed in all positions. Per volume of weld metal FCAW has the lowest heat input of the processes applicable to the configuration being designed.

IV. RESULTS

The background signal (Figure 1) shows a clean test chamber. The results of the out gassing tests showed very similar results between the all of the welding processes.

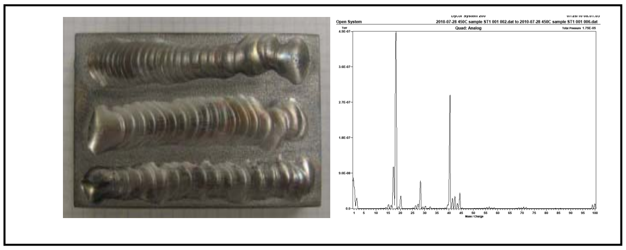

Figure 2. *GTAW Weld*

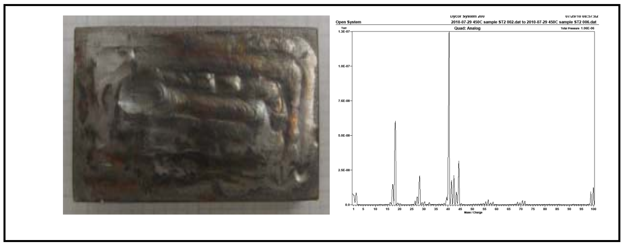

Figure 3. *GTAW Fusion Weld*

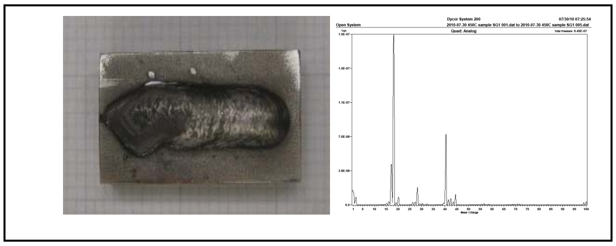

Figure 4. *GMAW Weld*

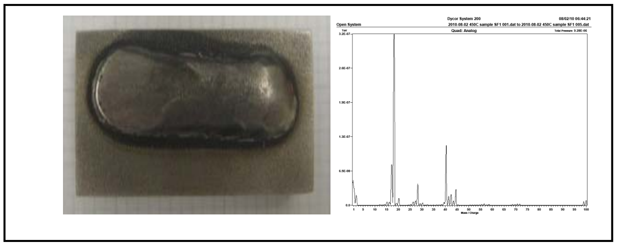

Figure 5. Chroma Weld 316LT1

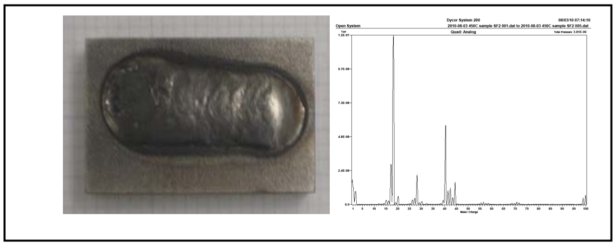

Figure 6. *Goldcor 316LSi*

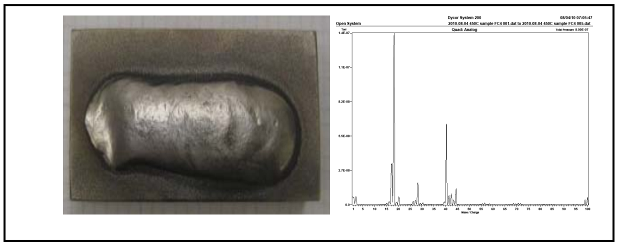

Figure 7. Shield-Bright 316L

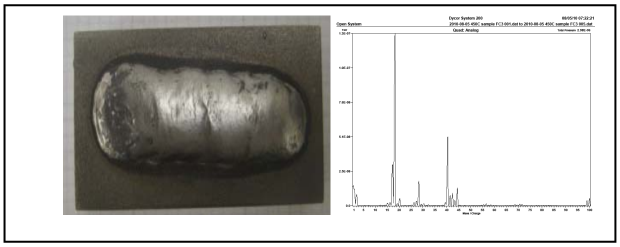

Figure 8. Arcaloy MC 316L

A sample of un-welded FCAW wire was tested in order to determine its chemical composition.

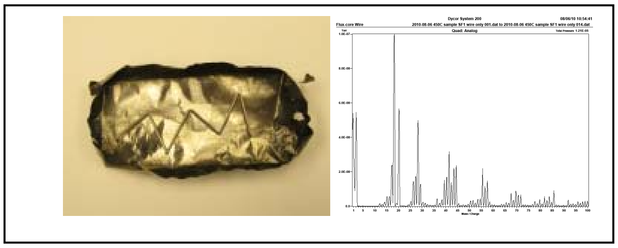

Figure 9. Un-welded FCAW Wire

I. Conclusion

Flux Cored welding has the capability to deposit maximum weld metal with minimal heat input and thereby create the least amount of distortion. In the testing preformed, the out gassing qualities were very similar among the several brands of wire tested. The types of compounds out gassed were similar to those of other types of welding. The quantity of these compounds did vary between processes. The time to reach steady pressure was slightly longer for the flux core, 40 minutes compared to 25 minutes. Flux cored welding appears to be suitable for use in a high vacuum environment. With some further testing flux cored arc welding will be fully qualified for use within the NSTX vacuum vessel.

II. Future work

In order to better simulate actual vacuum vessel conditions, larger samples will be tested. These samples will be prepared as the welds in the torus will be. This involves cleaning, which will be done with rotary wire brushing, grinding and, wiped down with alcohol. The samples will only be heated to 150°C. Slag from the weld will also be test to determine the out gassing properties of it.

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