Application of Laser-Manufacturing Technology to Fabricate Square Tubes for Multi-Purpose Canister

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ABSTRACT
The UMS/MPC transport/storage system developed by NAC International consists of a multi-purpose canister that is called the Transportable Storage Canister, which holds spent fuel in an orderly manner to maintain sub-criticality, and a concrete over-pack for storage. The multi-purpose canister consists of a basket, a thin wall container shell and a double lid system. The basket consists of thin wall square tubes, and support and heat transfer disks. The components required highly accurate fabrication to obtain a high-density fuel assembly payload.

In the US, several nuclear power stations have been under decommissioning programs and a large quantity of storage systems are required at one time to move the spent fuels from an existing storage pool to an above ground storage pad at the nuclear power station. As the canisters contain 30 to 40 fuel assemblies, and 40-50 canisters are necessary for one project, more than one thousand square tubes must be fabricated.. To cope with this demand for large quantities of tubes in a short period of time and severe tolerances, laser beam welding technology has been developed and applied to fabricate a large number of thin wall square tubes.

The development and application of the laser beam welding technology to the fabrication of a thin wall square tube is explained in this report. The square tube is made of thin wall stainless steel plate and has a double paneled structure of the tube body and cover for the neutron absorbing material The tube body is obtained by welding two C shaped stainless steel plates with a butt joint welds, and the neutron cover is fitted to the four sides of the tube by a continuous fillet joint weld.

Using laser technology, multi-purpose canisters, which satisfy all design requirements, are achieved.

INTRODUCTION
The basket assembly of the multi-purpose canister consists of thin wall square tubes, and both support and heat transfer disks. The components need to be fabricated with a focus on maintaining accurate dimensions in order to obtain the highest possible density of fuel assemblies.

The canister contains space for 30 to 40 fuel assemblies, and 40-50 canisters are necessary for one project, requiring more than one thousand square tubes. To meet the quantity, quality and time demands, laser beam welding technology was developed and applied to fabricate a large number of thin wall square tubes with severe fabrication tolerances.

MULTI-PURPOSE CANISTER
The Universal Multipurpose System (UMS) and its very similar predecessor, the Multi Purpose Canister System (MPC), both of which were developed by NAC International, is shown in Figure 1. The Transportable Storage Canister (TSC) inside the concrete overpack can been seen in the cutaway view. The (TSC), which is a multi-purpose canister is one of the principal components for the system and consists of a stainless steel canister and a basket assembly.

Stainless Steel Canister: The canister is serves as confinement for the spent fuel during storage and has a double welded lid closure system. The major components of the canister are the shelland bottom, shield lid, and structural lid. The canister and the shield and structural lids provide a confinement boundary during storage. The canister shell and bottom are Type 304L stainless steel. A basket assembly is placed inside the canister. The shield lid assembly is a Type 304 stainless steel disk that is positioned on the shield lid support ring above the basket assembly. The structural lid is a Type 304L stainless steel disk positioned on top of the shield lid. The lids are both welded to the shell after the fuel loading.

Fuel Basket: The basket assembly showed in Figure 2 provides the structural support and primary heat transfer path for the fuel assemblies while maintaining a sub-critical configuration. It is constructed of stainless steel, but incorporates aluminum disks for enhanced heat transfer. The fuel basket is a right-circular cylinder configuration with square fuel tubes laterally supported by a series of support disks. The basket traps the fuel tubes between the top and bottom weldments, thereby preventing axial movement of the fuel tubes.

Support and Heat Transfer Disks: The disks are retained by a top nut and supported by spacers on tie rods at eight locations. The support disks are fabricated from Type 630 stainless steel. The disks contain square holes for the fuel tubes as shown in Figure 3. The bottom weldments are fabricated from Type 304 stainless steel and are geometrically similar to the support disks. The support disk configuration includes webs between the fuels. The heat transfer disks are made from Type 6061 aluminum alloy. The heat transfer disks are spaced and supported by the tie rods and spacers, which also support and locate the support disks. The heat transfer disks, located at the center of the axial spacing between the support disks, are sized to eliminate contact with the canister inner shell taking into account differential thermal expansion.

Square Fuel Tube: The square fuel tubes are fabricated from Type 304 stainless steel. The stainless steel is formed into C's and then welded together to make tubes. Boral sheets are placed on each side of the square tube, and secured to the tube with a thin shaped stainless steel covers that are welded to the tube. The Boral provides criticality control in the basket. The wall of a fuel tube is 1.2 mm thick stainless steel, and the stainless steel cover layer over the Boral is just 0.5mm thick. A cross section of the tube is shown in Figure 4. The fuel tubes are inserted into the square holes in the disks where just 1mm clearance is allowed between inner dimension of the holes and outermost dimensions of the square tube throughout the tube length of 3,000 mm, so that a straight square tube with as little distortion as possible is required. The requirement of such a severe tolerance is the result of the economical-based demand to load the maximum number of square fuel assemblies into a cylindrical canister.

LASER BEAM WELDING

The thickness of the stainless steel square fuel tube and the stainless steel cover for the Boral sheet are 1.2 mm and 0.5 mm respectively. Traditional methods such as TIG produced unacceptable distortion causing the tube to display out of square and non-straight characteristics that exceeded the required tolerance. So, laser welding technology was adapted to minimize welding distortion and obtain a high degree of accuracy in producing straight square tubes for the fuel basket. Figure 5 is the Continuous Wave YAG laser beam welding equipment applied to fabricate the square fuel tube. The equipment consists of YAG laser resonator of maximum output of 4 kW and average of 2 kW, a working station with a 6 axis robot, and a real time seam tracking system with 10ìm resolution that is necessary for automatic welding operation. ASME Sec. QW-264 requires that fluctuations of both the laser output at the working and focus point, and the flow rate of assist gas shall be managed within 5%, so that digital flow meter and a laser power reflection monitor were added to the equipment.

Size of Groove: Figure 6 shows the relation between groove size and throat thickness for both butt and fillet welding. Through experimentation, it was determined that the size of the groove for both butt and fillet welds should be not more than 0.1mm to obtain the minimum throat thickness required by the design specifications.

Confirmation of Output by Monitoring the Laser Power Reflection: As mentioned above, ASME required the laser power shall not exceed by more than 5% fluctuations. Real time monitoring of the laser power at the working point proved to be quite difficult, so the welding procedure specified that the output before and after welding is to be monitored to confirm that the fluctuation is within the requirement. In addition to that, the relationship between the contamination on the protection glass and the laser power reflection were examined because the contamination may reduce the laser power at the working point. Figure 7 shows the result, which indicates loss of the laser power by 4% when the glass is contaminated and the digital monitor of the reflection power shows 25. The timing of the cleaning of the protection glass was determined from this result to prevent the power reduction by the contamination.

PERFPRMANCE OF WELD BY LASER WELDING

Cross Section: Figure 8 shows the cross section of both the butt and fillet weld joints resulting from using the laser beam welding equipment. No defect and/or flaw is observed in the weld and it satisfies ASME requirements.

Mechanical Test: Mechanical test results are shown in Table 1. The tensile test was performed on T1 and T2 butt welds and it was confirmed that the strength exceeds the required strength of the base metal (515 MPa). The bending test was carried out on B1, B2, B3, and B4 butt welds and confirmed that no crack was observed in the test specimens.

Table 1 Mechanical Test Results

Joint	Tensile Strength (MPa)
T1	626
T2	658
B1	no defect
B2	no defect
B3	no defect
B4	no defect

Quality of the Laser Weld: Figure 9 shows the results of EPM Analysis on Cr, O and N at 0.1 mm below the surface of both a laser weld and TIG weld. The weld width of the laser weld is 1.2 mm, and that of the TIG weld is 4 mm. The analyzed signal levels of Cr, O and N in the laser weld is same as those of the basic metal. On the other hand, the level of those elements in the TIG weld varies widely compared to the base metal. From this result, the quality of the laser beam welding is confirmed to be superior to that of TIG welding.

FABRICATION OF FUEL SQUARE TUBE

The square fuel tube is fabricated from two C shaped plates. The two C shaped plates are fixed together by tack welds and clamped down onto the working table. The laser welding is carried out automatically by using the real time seam tracking system. The system is also useful to adjust the focus point at the end of the tube. The tube in the Figure 10 is shown just after the completion of the longitudinal butt weld. No welding distortion is observed and the fabrication tolerance is within the design requirements. The tube is transferred to the working table, the Boral sheet is placed on a side of the tube and the fillet welding of the stainless steel Boral sheet cover is done after dimensional inspection. After the fillet weld, visual, dimensional and leak inspections are carried out on the square tubes, and compliant tubes are delivered to the basket assembling area.

Fig 11 is a completed fuel basket. Each square tube is inserted into each square hole in the disks from the top. After completion of all the tube inserts, the top and bottom weldments are fixed to the basket assembly. The high accuracy dimension of the square tubes makes the assembly work easier and shortens the working time.

SUMMARY

By applying laser beam welding technology to the square fuel tube fabrication:

- a straight non-distorted accurate double paneled square fuel tube is obtained,
- high speed and automatic welding is realized,
- assembling the fuel basket is easier and the working time is shortened,
- and the TSC can be delivered on schedule.

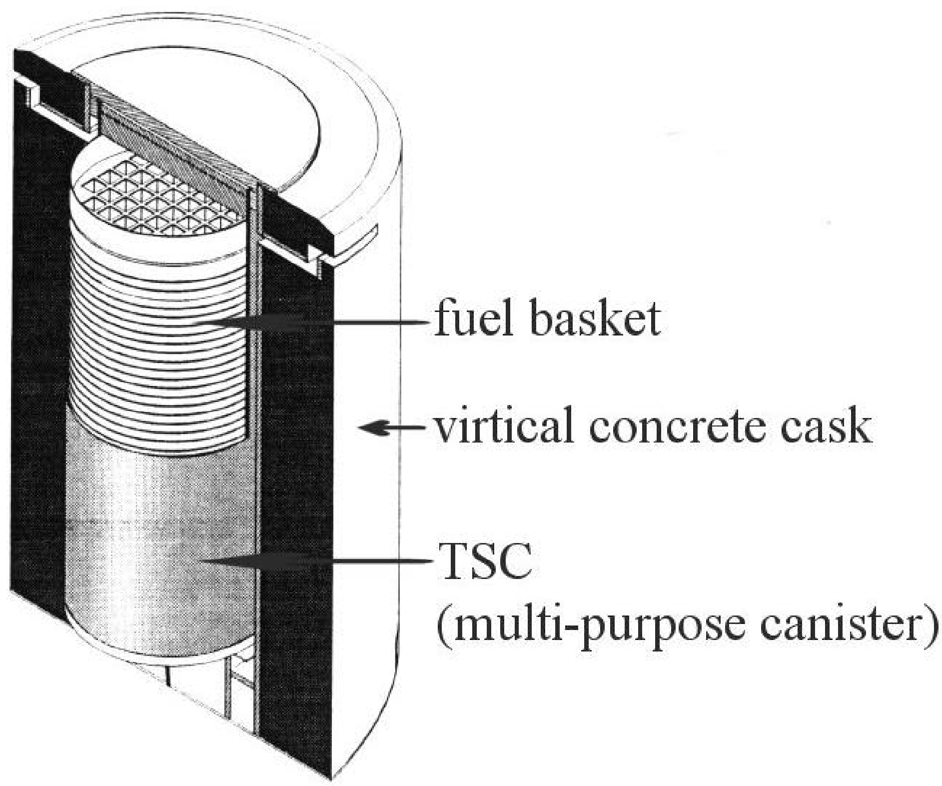


Figure 1 UMS/MPC for Fuel Storage System

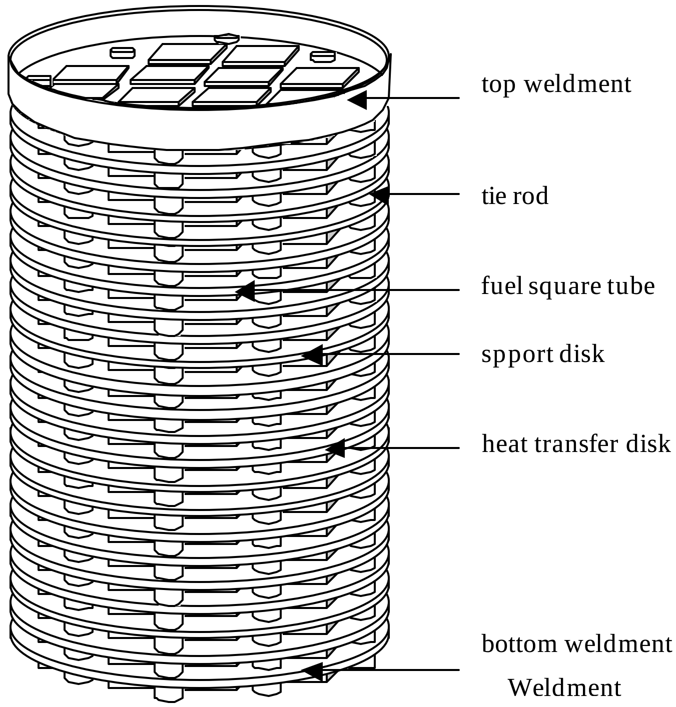


Figure 2 Schematic Diagram of Fuel Basket

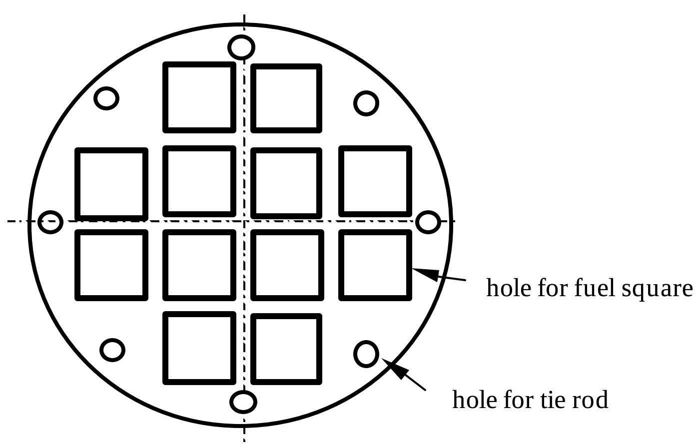


Figure 3 Schematic Diagram of Disk

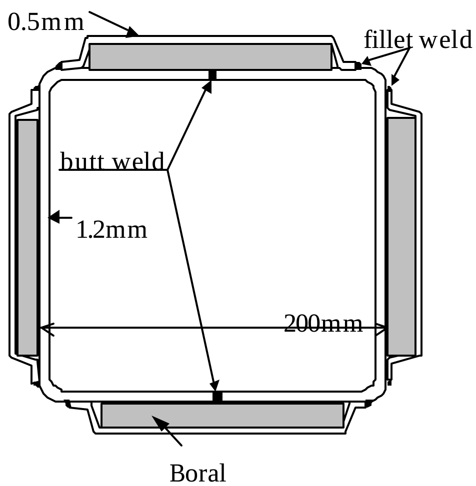


Figure 4 Cross Section of the Fuel Square Tube

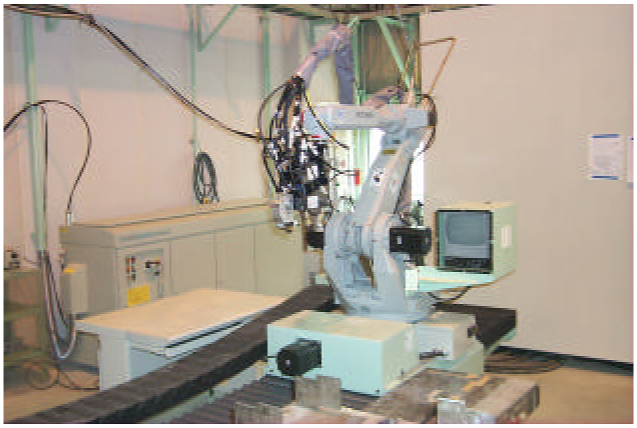


Figure 5 Laser Beam Welding Equipment

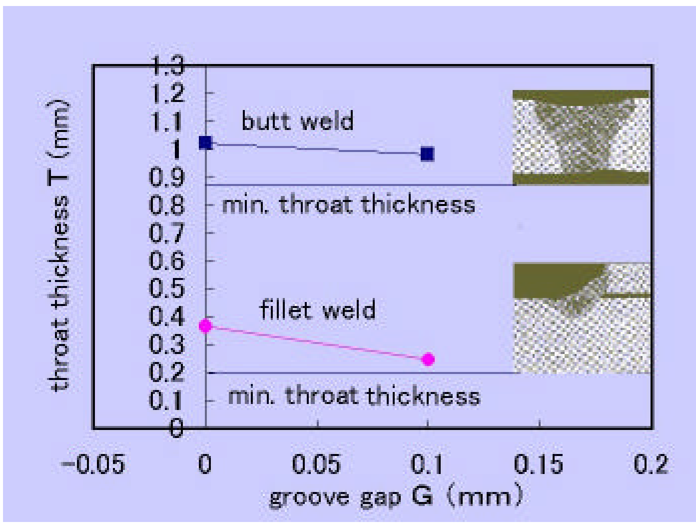


Figure 6 Relation between Groove Size and Throat Thickness

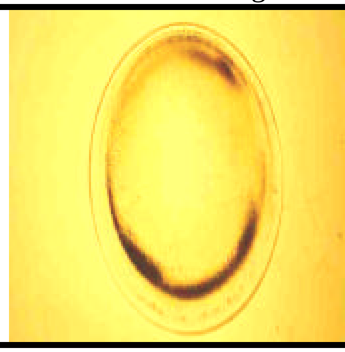
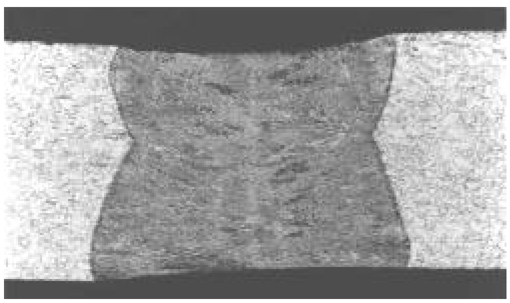
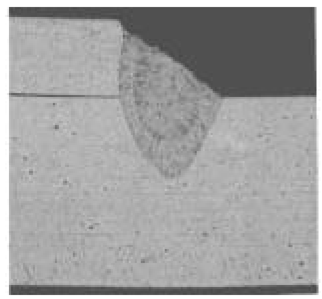
	before cleaning	after cleaning
protection glass contamination		
laser output reflection		

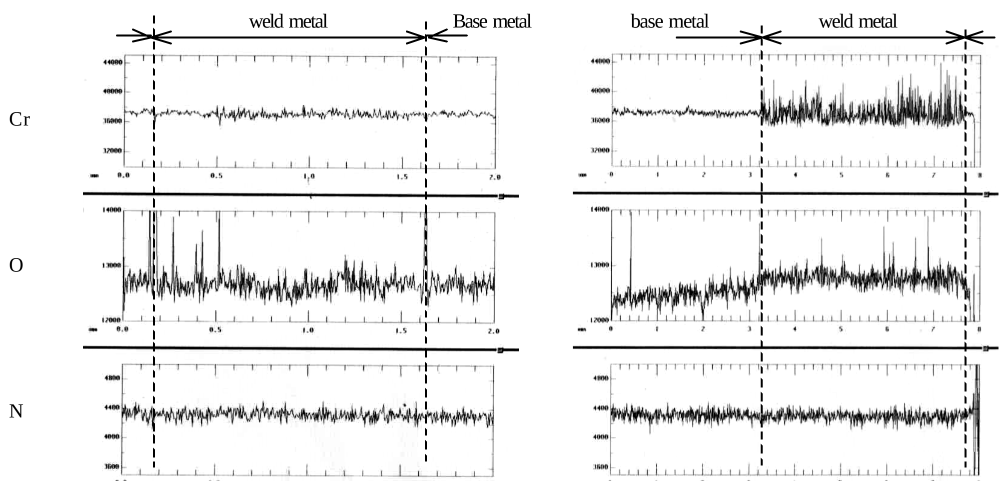
Figure 7 Relation between the Laser Power Reflection and the Contamination on the Protection Glass





butt joint fillet joint

Figure 8 Macro Cross Section of both Butt and Fillet Welds



(a) laser welding (b) weld

Figure 9 EPM Analysis of Laser and TIG Welds

Figure 10 Fuel Square Tube after Longitudinal Butt Welding

Figure 11 Fuel Basket