Friction Stir Welding (FSW) of Littoral Combat Ship Deckhouse Structure

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ABSTRACT

The United States Navy's Littoral Combat Ship (LCS) represents a new direction in military capabilities and ship design. The LCS's aluminum superstructure and deckhouse reduces weight and lowers the center of gravity of the ship. Arc welding aluminum is subject to distortion requiring non value straightening activities to be utilized. Friction stir welding (FSW) a welding process invented in 1991 at TWI in the United Kingdom is a solid state welding process that has considerably less weld distortion. It results in more affordable fabrication and inspection of the butt joint weld root. Details of the FSW process development, certification and fabrication of the LCS super structure and deck house are described. Experience with FSW on the LCS has resulted in a number of new fabrication ideas and concepts to improve affordability of future LCS and other aluminum ship structures.

Friction Stir Welding (FSW) Background

Since its invention in 1991, the FSW technology has steadily been enhanced and improved to allow the technology to be used in an increasing number of production applications. The first production application was initiated in 1995 by Marine Aluminum (Hagesund, Norway) and involved the FSW welding of 6xxx aluminum extrusions to make large panels for decking of fast ferries. An example of such decking is shown in Figure 1.

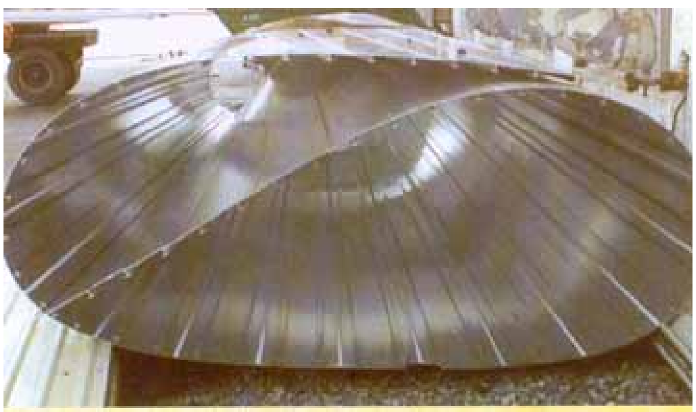

Figure 1 Fast Ferries Decking Rolled for Transport

Since this time, the use of FSW expanded into other applications, with many involving joining of extrusions to form larger panels for applications such as aluminum rail cars.

More recently the process has expanded into fabrication of more complex assemblies for the automotive, medical, semi-conductor, oil and gas industries. To date, most of the applications have involved welding of aluminum, but in the last couple of years the first production applications involving FSW welding of copper and steel have been initiated.

Basic Principles of Friction Stir Welding (FSW)

Friction Stir Welding (FSW) is a solid state welding process where a machine rotates a FSW tool, plunges, and then traverses through material of choice and along a joint to form a weld. The rotation action and the specific geometry of the FSW tool generates friction and mechanical work of the material which in turn generates the heat and the mixing necessary to transport material from one side of the joint line to the other. The process has significant advantages over other joining technologies and can be used to weld numerous materials including, but not limited to aluminum, copper, titanium, steel, magnesium, and plastic.

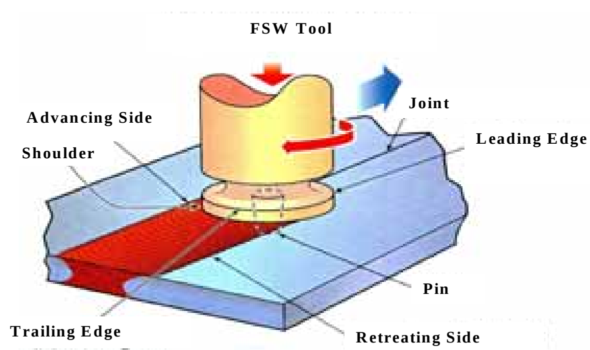

Figure 2 Diagram of Friction Stir Welding Process

Basic friction stir welding process steps consist of the following:

1. Tool Rotation Starts
2. Plunge Tool into Joint until Shoulder Contacts
3. Tool Traverses along Joint
4. Stop Traverse
5. Retract FSW Tool

Friction stir welding is a solid state joining process that requires significant forces ranging from 500 to 10,000 pounds. These loads applied to the FSW tool require robust support fixturing as well as high part clamping forces to keep the butt joint together as the FSW tool engages the weld joint. A hole results when the FSW tool is retracted from the work piece being welded. A plan to manage the effects of this range from removing it from the weldment, to using a plug welding technique to fill the hole as well as run on and run off tabs.

Typical Friction Stir Weld Joint Designs

Friction Stir Weld joint designs are important for Naval Architects and Marine Engineers to keep readily available. Those weld joints shown in Figure 2 are very easily adapted to friction stir welding. The typical fillet weld used in arc welding is not generally possible with ordinary friction stir welding tool designs.

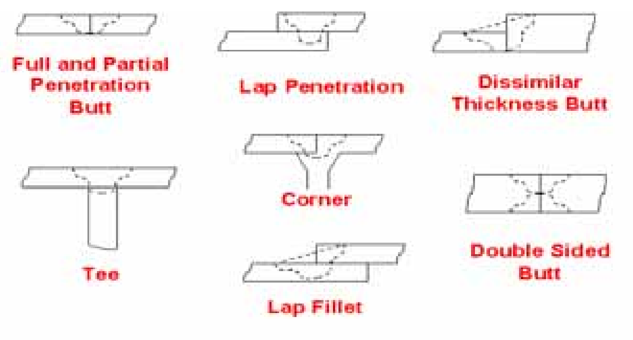

Figure 3 Typical Friction Stir Weld joint Designs

Certification of the FSW Process

Each friction stir welding procedure specification (WPS) must be documented in accordance with the latest American Welding Society ANSI/AWS D1.2-XX Structural Welding code - Aluminum. Procedure Qualification Records (PQR) for each WPS must be recorded as well. The Certifying Agency will sign off on both the WPS and PQR for the production welding of components to meet the design of the ship or LCS being fabricated. The American Bureau of Shipping (ABS) is one of the certifying agencies. Dye penetrant inspection of the weld root as well as radiographic inspection maybe required in some cases. A production quality sampling plan must be developed and implemented to insure consistent quality. On the LCS the ability to inspect the butt joint root is considered valuable to assuring a weldment of the highest quality. When aluminum panels are made by friction stir welding extrusions together, the extrusions must be checked to be sure they meet the specifications that will result in a panel that will not cause extra non value operations to be performed on the shop floor. One plan is to sample initially at a high frequency and reduce the number of production weld samples as the process becomes stable. In the case of the LCS, a test specimen was removed from the end of a weld on every third panel and finally every fifth panel welded. The test specimen provided for a joint tensile and a root bend test with the specimen containing the FSW tool hole at end of the weld being discarded. Production friction stir welds can have undesirable flash due to thickness variation of the extrusion. Flash can be removed by grinding, disc sanding or other appropriate means. Flash generally does not affect FSW strength; however, it may cause workers to be cut or scraped causing injury. Friction stir welds up to fifty feet long can be produced. Length and width of FSW extruded panels is often dictated by the logistics of getting the panel from the FSW provider to the shipyard.

Construction of the LCS Super Structure

Flatness of the friction stir welded panels proved to be valuable to build the LCS Deckhouse and eliminated non value added straightening operations. Handling and storage of FSW panels is a critical operation if the flatness is to be maintained. One improper lift or improper blocking when stacking can induce permanent distortion. Planning the workspace in advance of production start is essential to success. Design details such as width of panels between deep stiffeners should be considered to maximize the ability of the structure to help hold the flatness and desired shape. The Keel laying ceremony was June 2, 2005 on LCS and the aluminum deckhouse structure was started then also. The initial phases of the LCS deckhouse taught hard lessons on many shop practices that worked on steel, but were marginally useful on aluminum. Gas Metal Arc Welding (GMAW) has been the preferred process to date when welding aluminum. The application of GMAW to the panels was required to produce the panel width in excess of the FSW panels that had to be transported to the shipyard. GMAW has the three modes of distortion common to most arc welding methods. Transverse shrinkage occurs across the width of the panel and causes difficulty fitting frames over the stiffening members. Longitudinal shrinkage causes "puckering" of the panel along the length of the weld seam. Rotational distortion also causes "puckering" of the panel but is evidenced on a local basis between framing members. Welding sequences, minimizing heat input and other factors can help control these three modes, but distortion will still be a major cost driver. Joint design is also a factor in reducing distortion. To help hold shape and reduce cost a lap joint was designed that would be fillet welded on each side. The lap or backing was made in the extrusion and added to the edge of panels during the FSW production runs. This type of joint produced the least amount of distortion during prototype weld testing. When compared to a full penetration butt weld the distortion was about 60% of what was encountered during butt welding. Strength considerations of the lap joint were examined and considered adequate for the design. When production welding started it was rapidly apparent the even the 60% distortion factor of the lap joint was a problem. Clamping of panels and using weights to hold flatness could reduce the distortion, but total elimination was not possible. Many initial lap joints "puckered" in the length direction from overall shrinkage. Rotational distortion at the ends of panels once released became a problem. Panels would "spring" up or downward when released due to residual stress from the GMAW process. In some areas the panels encountered 20 millimeters of distortion when measured between frames. This required cutting the GMAW welds out, re-fairing the area, then re-welding with GMAW in a skip weld pattern to reduce heat input and distortion. The longer the weld length with GMAW the more areas that “puckered” due to residual stress induced distortion. FSW does not seem to have a problem in this respect. The length of the joint up to 50 feet as observed remained flat. It was observed that panels with extruded shapes such as “Tee”s reduced the distortion encountered with GMAW. The flat-bar type panels were the most rework intensive with a 20% factor being encountered as an average. There were also times where panel assemblies were erected into the module and during the fitting process areas distorted. When welding the GMAW erection joints these areas expanded if not carefully monitored and controlled by skip welding or other techniques. Rework at this phase was costlier due to the scaffolding or man-lift required to safely accomplish the work. The resulting deckhouse fabrication modules were within tolerance and the end result was pleasing to the eye. GMAW joints still could be picked out at a distance due to some rotational distortion, but overall flatness was achieved. The specific standards are contained in the ABS Naval Vessel Rules 2005, and the LCS Ship Specification document. The interior panels were thinner due to design and distortion was harder to control due to that factor. The deckhouse structure above main deck is all aluminum joined with a bimetallic joint. It includes the hanger bay for two aircraft and other equipment. This area was also harder to control due to the minimal framing support that could be provided and maintain the open envelope for aircraft movement. The Navy sponsored research programs in FSW and now the concepts have been proven in a full scale structure. More improvements can be attained and designs can be adjusted to make full use of FSW to maintain flatness and reduce weight.

Affordability Improvement Ideas

One idea to improve affordability would be to fabricate standard structural shapes such as "Tees", "I" beams, and channels. In the case of fabricated "Tee"s the stem of the "Tee" could have pre-punched holes or other cut out shapes. This would eliminate cutting holes in pre-fabricated panels on the shop floor. Sheet also has better and consistent thickness repeatability. Another way to improve affordability is to manufacture panels by using roll formed or press brake formed hat sections FSW welded to sheet. Hat or other formed shapes could be filled with insulation to aid in designing for improved fire protection. Friction stir welding does not degrade or produce fumes from most insulating materials. A major affordability improvement could be realized with a portable friction stir welding machine transported to the shipyard and operated by the FSW contractor in conjunction with shipyard personnel. This could reduce shipyard capital and permit FSW welding of aluminum panels to size. Erection joints could be planned to allow access for the portable FSW machine. This would further reduce distortion in the final ship structure and reduce erection rework costs considerably. Panels FSW welded to the correct length and width could eliminate GMAW weld costs and distortion as well as reduce scrap.

Conclusions:

1. Friction stir welded aluminum panels are very flat.
2. Friction stir butt weld root is clearly visible for inspection.
3. Gas Metal Arc Welds used to join aluminum panels cause distortion.
4. Extrusions must be checked to be sure they are within specification.
5. Lower welding costs can be realized with friction stir welded panels.
6. In shipyard FSW equipment can lower capital investment and reduce aluminum panel cost with large panels made to suit.
7. Fabricated aluminum panels from sheet and formed hat shapes could reduce costs.
8. Fabricated panels with hat shaped sections can be filled with insulation to control fire hazards.

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