STANDARDIZED WELDING CURRICULUM AND TESTING FOR SHIPYARDS

Technology Investment Agreement 2005-337

FINAL REPORT

Revision 1

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Introduction

The National Shipbuilding Research Program (NSRP) project entitled "**Standardized Welding Curriculum and Testing for Shipyards"** is an NSRP Workforce Development Panel Project that aims to train shipfitters and welders with a collaborative and sustainable optimization process on weld size control and production process improvement. Ingalls Shipbuilding (Ingalls), a company element of Huntington Ingalls Incorporated (HII), is pleased to provide leadership for this project. It is intended to significantly reduce the cost of lightweight steel production across the U.S. shipbuilding and ship repair industries. This project is applicable to a major labor cost driver across all shipbuilding and ship repair programs. The team expects the results of the project to be applied to Ingalls programs such as DDG, LHA, LPD, and USCG NSC, and to be transferred to all Navy, Coast Guard, and Repair Programs upon completion of the project.

In recent years, ship designers have been forced to incorporate lighter, thinner steel structures to reduce topside weight, improve fuel economy, and enhance mission capability. Over the past decade, the production ratio of thin-steel (10 mm or less) to thick-plate structures for some vessels built at Ingalls has risen up to 90% per ship. At the same time, military and commercial customers have tightened the design requirements in strength, stiffness, and fitness to meet more stringent performance specifications.

Understandably, the development of technology, facilities, and processes to build thin steel ships efficiently has not kept pace with the rate of change in the designs. Shipbuilding facilities and equipment are large, costly, and expected to have a long service life. Thin steel requirements affect facility issues from the spacing of conveyor rollers, to the type of magnet cranes used, to the way steel is stored, cut, moved, welded, and assembled. The heavy machinery and support structures that are part of the steel fabrication facility cannot be changed overnight. The rapid shift in the use of thin steels from small percentages a decade ago to the high levels of today poses a major cost challenge to the U.S. Navy, to Ingalls, and to other U.S. shipyards that build these ships (Ref. Huang, 2003, 2005; Spicknall, 2005, 2006).

Project Background

Shipyard training programs are varied in their methods and in the metrics they use to qualify welders, and welders are not always trained on each type of weld (i.e., butt, fillet, lap, or a small precision one-pass weld) before going out into the field and performing them. As naval ship designs continue to incorporate a rising amount of thin steel, the demand for a standardized training program to address the requirements for welding this thinner material is increasingly apparent. In many programs, little attention is given to distortion control practices, during fitting and welding processes.

Funded by NSRP on January 6, 2013, this project will investigate what is currently taught in U.S. shipyard training programs in order to determine where change is most-needed. Working with shipyard instructors, a new program was drafted and tested at Ingalls with the goal of training welders who are able to make sound welds to design sizes and who are capable of performing welding procedures needed for current modern lightweight ship production in order to reduce rework and downstream costs. An “as-is” analysis of the current state of weld training and curriculum given to new hire welders and re-training for current welders employed at Ingalls has been performed. Investigation of the current state at Ingalls and other US shipyards has led to affirmation of the need to fully develop and implement an optimal training strategy to address the issues faced by welders in today’s ship designs and production limitations. It’s expected that the benefits the standardized weld curriculum will bring to cost savings at Ingalls Shipbuilding and across all other U.S. shipbuilders will be substantial.

Project Deliverables

There were 6 major tasks achieved throughout the project:

- **Task 1**: Shipyard Survey
- **Task 2:** Draft Curriculum Development
- **Task 3:** Pilot Training Implementation
- **Task 4:** Observation of Results
- **Task 5:** Curriculum Adjustments
- **Task 6:** Deliver Final Report

The detailed task accomplishments and deliverables that were completed are outlined in the coming sections.

Shipyard Survey Report

HII-Ingalls developed a training survey questionnaire based on current needs for modern naval ship production through investigation and documentation of proven techniques (Ref. Huang, 2004, 2007; Conrardy, 2006). The survey questionnaire was sent to 11 US shipyards regarding their current welder training programs to determine where curriculum focus would be most beneficial. In addition to HII-Ingalls, the project team has received formal survey responses from Bollinger, BIW, HII-Newport News Shipbuilding (HII-NNS) and Vigor. The compilation of these responses was incorporated into the course outline. Focusing the training modules based on the survey feedback allows the project team to address areas that are most needed and training that will generate the greatest benefit to the US shipbuilding industry.

The survey results show that the current weld training programs across the US shipbuilding industry have significant deficiencies in welder and fitter training specific to distortion control in lightweight ship production. In addition to the written responses to the survey questionnaire, shipyard educators at several other yards provided verbal feedback. The consensus from these yards was that no formal training on thin steel fitting and welding techniques exists in their respective organizations. The training personnel at these shipyards expressed a desire and need for a standardized curriculum to address the welding issues present in the majority of today's ship design and construction. Based on the information obtained from these shipyards, numerous production issues were found to be related to current fitting and welding processes which are mostly due to a lack of adequate training.

In most cases, only limited supplemental guidance on fit and weld best practice techniques for specific distortion control are available for welders. In addition to an overall lack of formal training on thin steel and distortion control, several specific areas were isolated as particularly needed for inclusion in the curriculum. Examples of these module topics include: tack quality, root gap tolerances, minimizing overwelding caused by gouging processes, insert fitting procedures, weld sequencing, and achieving design specified weld sizes. These topics will be investigated in depth and adequate training procedures will be developed and included in the modules.

The shipyard training questionnaire that was sent to the major US shipyards as well as the responses received from participating yards is included in Appendix 1.

Standardized Welding Curriculum

HII-Ingalls completed an initial draft of the Standardized Welding Curriculum in October 2013. The curriculum topics and modules were chosen based on current thin steel production needs. Ingalls surveyed the current new hire and recertification training program for fitters and welders and identified areas where key information pertaining to welding thin steel ship designs was neglected. Those topics as well as training information gathered from surveying other major US Shipyards allowed the team to set an outline for topics to be covered in the curriculum.

The topics that need to be covered fell into four major categories: First Time Quality, Welding, Shipfitting Plates and Inserts, and Quality Inspection. These categories formed the foundation of each module and in all, the curriculum contains four modules targeted at 2 to 4 hour training sessions each. Information critical to thin steel production and distortion mitigation for each of the modules was obtained through extensive research, process review, discussions with subject matter experts, and on-site production observations. Each module was thoroughly developed based on the information gathered and course material was put into PowerPoint format.

Much of the subject matter pertinent to the modules is advanced and highly technical. Realizing the curriculum needs to be comprehensible to a wide range of education levels, the subject matter was broken down to verbiage that could be easily understood and applied. A focus was made to reinforce abstract concepts with plenty of visuals and production examples. The project team generated graphics, inserted pictures, developed animation and provided videos to ensure the material was easily conveyed to the target audience. At numerous points throughout the curriculum, there is a knowledge check where the students are asked to recall important information from the module. The team made efforts to re-emphasize key concepts due to the complexity and quantity of new information being presented.

Testing the welders' understanding of concepts learned throughout the course will commence upon the completion of classroom instruction. A welding mock-up practical has been produced to give hands-on visual testing while exposing the welders to physical examples of defects and principles discussed in the course. The mock-up stands 5 feet tall and has divided sections to allow for up to 4 welders to be tested at a time. Each section contains different welded samples that demonstrate important items discussed in the course modules. The welder will be given the test that corresponds to the section they are inspecting and asked to identify the defect or problem with the sample as well as provide a brief description of probable cause and prevention measures. The draft curriculum deliverable report can be found in Appendix 11.

Training Videos

Three videos were developed for the curriculum and linked to the PowerPoint via hyperlink. The first video is shown in the First Time Quality module and was designed to give students an understanding of the importance of quality and distortion control. The video shows a background of quality and gives examples of how quality affects the worker as well as the final product. A case study on the USS Thresher is included to demonstrate how their production quality can translate to the safety of the sailors, the effectiveness of our ships to carry out their missions, and ultimately the protection of our country. The video is attached in Appendix 2.

The second video shows the proper procedure for using a weld gauge. At Ingalls, all welders are issued a fillet weld gauge and a cambridge gauge before starting production work. Often times welders negate using their gauges due to lack of training on how to use them correctly as well as misunderstanding the importance of using them to control weld size and rework. The video is attached in Appendix 3.

The third video demonstrates how to prep, weld, and control distortion with submerged arc tractor welding. The video captures common problems when performing this type of welding and discusses why certain circumstances encountered can be problematic and how they can be avoided. Best practices and tips for making quality welds that induce minimal rework are described as the weld is made to reinforce the concepts learned throughout the curriculum. The weld gauge training video attached in Appendix 4 will provide welders a visual tool to refresh their training on using a weld gauge correctly.

Additional Curriculum Material

In addition to the PowerPoint training modules and videos, several other items were developed to enhance the learning process and help the welders when they begin production work.

Course Topics

By extracting information obtained from surveying Ingalls and all other major US shipyards on current welding curriculum programs as well as from identifying common production issues, a course outline with 4 main topics was generated. The table below identifies the main course topics and subsequent modules that were developed based on Task 1 findings.

Table 1. Welding Curriculum Course Topics

Module	Title	Description	Length (hr)
1	First Time Quality	• Define residual stress and the correlation to distortion and rework. • Define FTQ and the importance of quality. (Video included)	2
2	Welding	• Describe to the welders what distortion is, the different types of distortion and the production challenges thin steel designs present. • Discuss the effects of overwelding vs. welding to design. • Illustrate common welding issues and distortion control techniques. (Video include)	4
3	Shipfitting Plates and Inserts	• Describe how cutting and fitting processes can cause distortion and welding difficulties. • Define fit quality and its importance in achieving adequate welding quality. • Demonstrate plate/insert fit-up and welding processes to reduce rework. • Describe proven welding sequence methods to improve quality.	2
4	Quality Inspection	• Identify common types of distortion. • Display distortion examples and test on potential causes, prevention and correction procedures. • Demonstrate the “trickle down” effects of distortion.	2

Testing and Qualifications

A plan to test the welders on the material learned in the classroom was developed based on an existing weld testing program in place at HII-NNS. The project team visited HII-NNS on August 27th, 2013 to gain an understanding of the welding curriculum and testing programs currently in place. There were numerous takeaways from this visit, one being an idea on how to test the welders on their understanding of the classroom material in each module. A plan to implement a modified version of this testing as the project's final welding practical upon conclusion of the four classroom modules was established.

HII-NNS shared their hands-on testing procedure with the team which consists of a mock-up structure built in 8 separate sections that allows for 8 students to be tested on different course material simultaneously. Each octant has a variety of structural coupons that the students must examine. HII-NNS uses their mock-up to test both structural welders and pipe welders on detecting weld flaws or other rejectable defects that may occur in production work. The project team admired the ability this method had of testing with a hands-on fashion and determined ways to adopt this concept to fit the material presented in the standardized curriculum for this project.

Final Welding Practical

The HII-Ingalls project team adopted the testing mock-up structure and several other key components from the example shown at HII-NNS and drafted up a recreation of the mock-up foundation in AutoCAD. The concept of separating the structure into 8 equal sections to test multiple students at once was used in the design and once the initial design was completed, it was issued to the HII-Ingalls welding school instructors to build.

The mock-up was built out of aluminum to make it as light weight as possible and the structure was mounted on 4 wheels to allow for easier transportation between classrooms. A list of welded samples that test the classroom material was developed and the team worked along with HII-Ingalls welding school instructors to create the test articles. The concepts for each sample were derived from the desire to have the welder identify thin steel distortion causing practices that they have been taught to avoid or correct in order to reduce rework cost or structural damage. Images of the completed mock-up are shown below. The coupon identification and descriptions are included in Appendix 7 and the testing forms are included in Appendix 8.

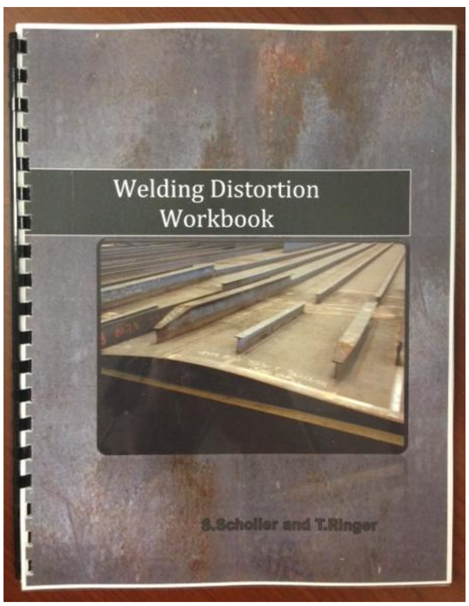
Each welder being tested is assigned a section of the mock-up to test on and is given a test sheet that corresponds to the coupons in that section. The welder is asked to identify the issue or distortion causing practice shown in each test article, record the probable cause of the defect, write down the corrective action needed to avoid further rework or process delays, and document prevention measures that should have been used to avoid the problem and achieve first time quality. The instructor contains a key that shows correct responses and each student is encouraged to interact with the instructor if there are discrepancies or if further explanation is needed. The mock-up successfully accomplishes the goal of giving the welders hands-on visual testing of actual structural components that they would see out in production and reinforce the distortion control techniques learned in the classroom by showing them examples of what they will physically see when on the job.

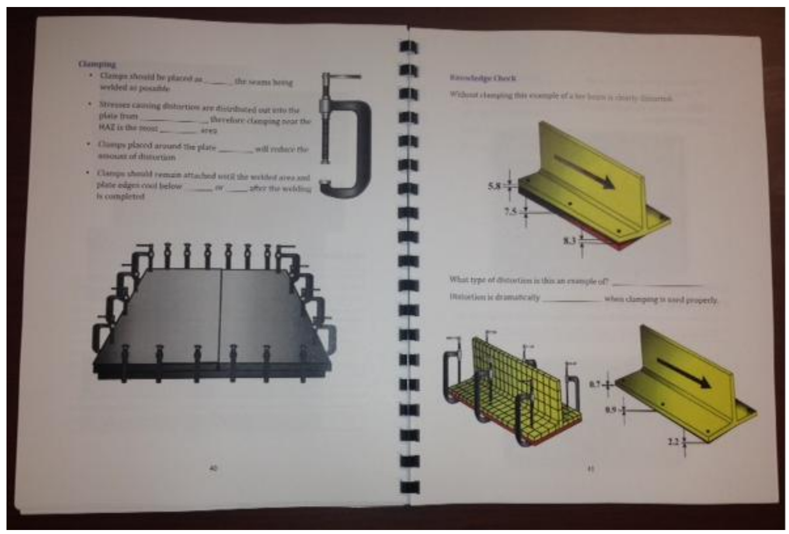
Knowledge Checks

Periodically throughout the classroom modules, students will be asked to complete quick knowledge check exercises. The knowledge checks act as a way to keep students engaged in the information presented to them as well as ensures the instructor that the students are gaining a full understanding of the course material. The knowledge checks afford the students an opportunity to interact with one another and open up discussion that helps build a foundation for remembering and applying the curriculum concepts.

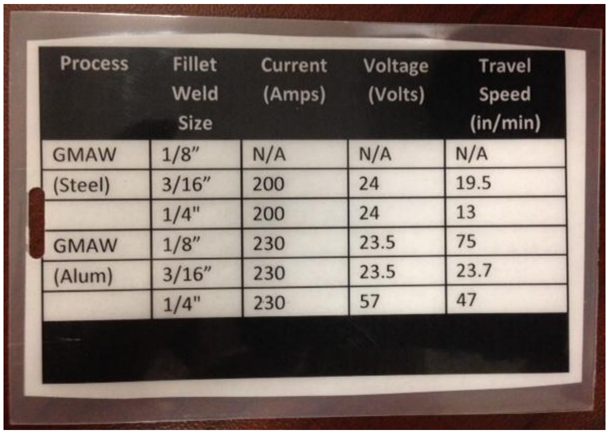
Workbook & Takeaways

A course workbook was created and will be distributed to each student to help maintain focus and enhance learning ability. The workbooks contain information and visual aids that follow along with the curriculum PowerPoint as the course is presented. Select items are intentionally left blank with room for the welder to fill in as they go along and there are designated areas to jot down notes or questions. By physically writing down key information from the modules, it helps stimulate the students' memory and ability to retain an understanding of what is taught to them. These workbooks will be given to the welders and taken with them as they transition into production to help reinforce concepts learned and access critical information needed to produce quality work. The workbooks are printed in a spiral bound booklet with laminated covers to maintain durability when referenced on the job. An image of the workbook is shown below and a complete electronic copy is attached in Appendix 5.

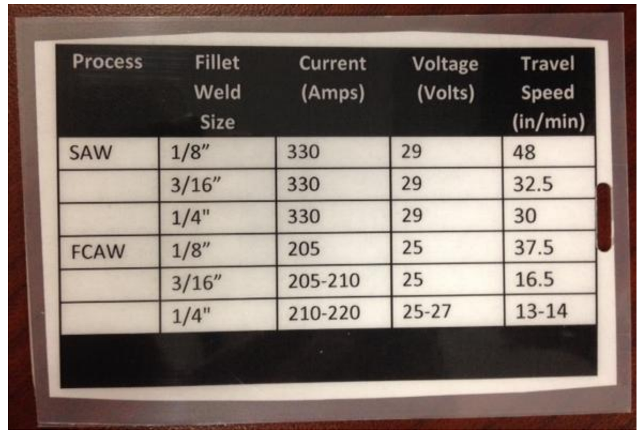




Welders will also receive a laminated card to place with their badge. This card contains recommended fillet weld settings for multiple welding processes to help them produce the smaller design welds that may otherwise be difficult to achieve with acceptable quality. Knowing that each machine will vary in its settings slightly as well as minor tweaks needed to account for welding in different positions, the cards can get the welder in the ballpark for achieving the proper design weld size. The cards issued to the welders are shown below.



Process	Fillet Weld Size	Current (Amps)	Voltage (Volts)	Travel Speed (in/min)
GMAW	1/8"	N/A	N/A	N/A
(Steel)	3/16"	200	24	19.5
	1/4"	200	24	13
GMAW	1/8"	230	23.5	75
(Alum)	3/16"	230	23.5	23.7
	1/4"	230	57	47



Process	Fillet Weld Size	Current (Amps)	Voltage (Volts)	Travel Speed (in/min)
SAW	1/8"	330	29	48
	3/16"	330	29	32.5
	1/4"	330	29	30
FCAW	1/8"	205	25	37.5
	3/16"	205-210	25	16.5
	1/4"	210-220	25-27	13-14

Pilot Training Results and Observations

A pilot training session was conducted on February 3rd and 4th 2014 and a sample of current welders were trained on the curriculum by shipyard instructors who were thoroughly briefed on the course and members of the project team. The project team was present during the training and interacted with trainees to gather information and make observations about the effectiveness of the curriculum in its current state. Feedback forms were given to the pilot trainees and the curriculum was adjusted based on the information gathered. The feedback forms are attached in Appendix 6.

The pilot training was limited to a small sample of production welders and foreman to maximize interaction and curriculum feedback. A welding foreman and a fitter and welder from each of the main fabrication shops as well as a foreman and welder from the waterfront erection area were selected to participate in the pilot training. The small group selected stimulated great interaction between the instructors and trainees and provided valuable feedback on both the content presented and the methods for which the material was presented to them.

The overall feedback from the trainees on the course was resoundingly positive. Each trainee identified with the need to bring this training to the shipyard crafts and provided enthusiastic examples where of how the current lack of training has affected their work and the overall quality and cost of production.

Curriculum Notes and Revisions

The project team received feedback on several concepts that were ineffective when presented as well as some changes or additions were made to addresses production needs. When observing the testing on the mockup, the pilot trainees offered ideas to include several other welding samples that could help future trainees visualize problems common to the production environment. One such addition, for example, was a plate that had tabs removed roughly along the seam that creates localized weld gap variation and generates avoidable weldability issues. The team took these recommendations and incorporated the changes to the curriculum as well as added the additional structures to the mockup. The pilot session was a great success and pivotal in improving the effectiveness of the overall course. The revised and finalized curriculum is included in Appendix 9.

Technology Transfer Activities

The project team attended numerous technology transfer activities to make the welding and shipbuilding communities aware of the efforts being taken to redesign a welding program that addresses the needs associated with today's thin steel ship designs. These events also allowed the team to solicit feedback and information from other US Shipyards on their current training programs and thin plate welding capabilities and deficiencies. Attending and presenting at these events was very beneficial in the success of this project and the interest generated from presenting shows promise in the number of shipyards that will take advantage of the finalized curriculum when released to NSRP. A summary of the events that were attended and where this project was presented are listed below.

NSRP All Panel Meeting: April 23-25, 2013 – Charleston, SC

NSRP Day: September 17, 2013 – Washington, DC

SNAME 2013 Annual Meeting & Ship Production Symposium: November 16-18, 2013 – Seattle, WA

NSRP Joint Panel Meeting: March 26, 2014 – Mobile, AL

NSRP Welding Panel Meeting: April 8-9, 2014 – Miami, FL

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Dave Bennett – HII-Newport News Shipbuilding

Dennis Fanguy – Bollinger Shipyards

Nick Evans – General Dynamics - Bath Iron Works

John Hitch – US Fab – Vigor Industrial

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T.D. Huang, P. Dong, L.A. DeCan, D.D. Harwig, and R. Kumar, “Fabrication and Engineering Technology for Lightweight Ship Structures, Part I: Distortions and Residual Stresses in Panel Fabrication”, *J. Ship Production*, The Society of Naval Architects and Marine Engineers, Volume 20, No. 1, February 2004, pp.43–59.

T.D. Huang, D.D. Harwig, P. Dong, and L.A. DeCan, “Engineering and Ship Production Technology for Lightweight Structures,” *Technology Review Journal*, Vol. 13, No. 1, Spring/Summer 2005, pp. 1–22.

M. Spicknall, R. Kumar, and T.D. Huang, “Dimensional Management in Shipbuilding: A Case Study From the Northrop Grumman Ship Systems Lightweight Structures Project”, *J. Ship Production*, The Society of Naval Architects and Marine Engineers, Volume 21, No. 4, November 2005, pp.209–218.

M. Spicknall, E. Hodges, and T.D. Huang, “Accuracy and Distortion Control Challenges in Lightweight Structural Unit Assembly at Northrop Grumman Ship Systems,” *J. Ship Production*, The Society of Naval Architects and Marine Engineers, Volume 22, No. 3, August 2006, pp.147–154.

C. Conrardy, T.D. Huang, D. Harwig, P. Dong, L. Kvidahl, N. Evans, and A. Treaster, “Practical welding Techniques to Minimize Distortion in Lightweight Ship Structures,” *J. Ship Production*, The Society of Naval Architects and Marine Engineers, Volume 22, No. 4, Nov. 2006, pp.239–247.

T.D. Huang, C. Conrardy, P. Dong, P. Keene, L. Kvidahl, and L. DeCan, “Engineering and Production Technology for Lightweight Ship Structures, Part II: Distortion Mitigation Technique and Implementation,” *J. Ship Production*, The Society of Naval Architects and Marine Engineers, Volume 23, No. 2, May 2007, pp.82–93.

Appendices

Appendix 1 – Shipyard Survey Report

Appendix 2 – First Time Quality (video)

Appendix 3 – Weld Gauge Training (video)

Appendix 4 – Tractor Welding (video)

Appendix 5 – Workbook

Appendix 6 – Pilot Training Feedback Forms

Appendix 7 – Mock-Up Test Coupon Descriptions

Appendix 8 – Mock-Up Answer Key

Appendix 9 – Final Curriculum

Appendix 10 – Curriculum PowerPoint (with instructor notes)

Appendix 11 – Curriculum Deliverable Report

Note: All appendix files can be found in the accompanying folder and are available through NSRP