

1. Objective

The objective of the guidance note is to identify the factors that influence accuracy of fabrication in welded ships and offer solutions to achieve the required levels of accuracy. The ultimate objective is to make the Australian fabrication industry more competitive by improving the quality of welded products and reducing fabrication costs.

2. Introduction

Shipbuilding involves the fabrication of large and complex welded structures. Hulls are made up from many plates joined by butt-welding with bulkheads and stiffeners welded to the inside surface only. The trend to block construction enables high levels of fit-out to be completed with minimal access restrictions. Piping and other services within each block must be fabricated with high accuracy to enable efficient integration into the structure.

Maintaining accuracy in overall dimensions of subassemblies is critical to the success of shipbuilding. The current trend to optimised designs using thinner plates and lighter stiffening creates greater challenges in accuracy control.

3. Accuracy Control Concepts

The purpose of a metal fabrication is to create the form, physical characteristics, and finish of a metal component according to clearly defined specifications. The fabrication process is executed by a group of people using available technologies and procedures. A measure of the effectiveness of the fabrication process is the ability to correctly produce specific parts that meet the specification.

3.1. Accuracy

The difference between the achieved mean dimension and the target specification is the accuracy of the process.

3.2. Variation

The variation of the distribution around its mean tells us to what degree the process is capable of achieving the desired performance; the smaller the dispersion around the process mean, the more capable the process. The reciprocal of the variance is the process precision, which measures the ability to execute identical performances and the ability of people and procedures to direct the fabrication process.

Variation arises from a multitude of sources. To overcome variance attributable to machines we strive for repeatability; to overcome variance attributable to people and procedures we strive for reproducibility. If we measure, for a single component and dimension, the means for sequential lots we would find that over time the mean of the process changes. The standard deviation over time of the process mean, defined as the stability of the process, is a measure of how well it performs over time. System variance is the net variance due to accuracy, repeatability, reproducibility, and stability.

Sources of variation are usually classified into two categories, random and systematic. Systematic sources of variation are those large enough to stand out, and can be associated with specific causes. Poor maintenance of a cutting tip, for example, could lead to an increase in the kerf width each time the tip is used, potentially causing a trend in the dimension from one part to the next. Random sources of variation are the "white noise" that results from a multitude of tiny causes that are not so easy to identify.

In fact there is no clear distinction between systematic and random sources of variation, although a useful simplification. Different sources of variation have different magnitudes and frequencies; the so called "random" sources are those so small that their sum is Gaussian (Normally distributed).

3.3. Process Control

Process control aims to reduce variation. Because manufacturers are unable to perform their processes repeatedly without any variation, some variation in dimensional accuracy is inevitable. Sources of variation lie in materials, machines, people and procedures.

A measure of the effectiveness of process control is the degree to which variation is minimised. The goal of process control is to limit variation; hence the application of process control requires an

understanding of the kinds of variation that can occur, their sources, and the means by which they can be managed.

Process control can be considered as comprising the following five activities:

3.3.1. Establishing Performance Standards

Performance standards are created when objectives are set during the planning process. Performance standards must be measurable and define the expected nominal result from a process. Tolerances (permissible deviation from the nominal) must be established to set the boundaries for acceptable product.

A fabricator creates the performance standards applicable to a task after consideration of all the information embodied in drawings, specifications and referenced documentation pertaining to the manufacture of the component.

3.3.2. Measuring Actual Performance

Process outcomes must be reliably measured using repeatable, verifiable techniques. This activity requires a degree of rigour in determining appropriate measuring tools, verification of the accuracy of the measuring tool, developing appropriate measuring techniques and procedures and ensuring competency of measuring personnel.

3.3.3. Comparison of Actual Performance Against Established Standards

Comparing measured values to performance standards determines variation. The measured value must fall within the agreed range of variation for the component to be acceptable.

3.3.4. Implementation of Corrective Action

The causes for deviation from the performance standard must be determined. Corrective actions must be implemented to minimise or eliminate the cause of non-conformance.

3.3.5. Continuous Improvement

Continuous improvement is a process that requires in addition to the above four steps, changes that are made are documented and become the way things are done from that point on. Changes could be made, for example, to drawings, specifications, manufacturing equipment, performance standards, procedures, processes or training. Without this important final step, improvements are reactive, short lived and do not effect a lasting change for the better.

4. Accuracy in Specifications

Specifications communicate the requirements of the customer to the fabricator and form the basis of a mutual understanding of the form and function of the finished fabrication. With clear specifications and objective standards with which to compare measurable outcomes, we would expect system variance due to inaccuracy to be markedly reduced.

4.1. Engineering Drawings

Engineering drawings contain most of the detailed information necessary to fabricate a component. Fabrication of complex structures requires drawings with sufficient detail to enable the fabricator to fabricate the components, sub assemblies and final product without having to make any assumptions or judgement calls.

Despite the best efforts of design and drafting personnel there are inevitably errors and omissions on drawings. Accuracy in fabrication requires good and timely communication between the fabrication group and the engineering group to quickly resolve issues as they arise.

Production pressures often dictate that production must proceed before issues are satisfactorily resolved with design authority approval. This leaves fabricators exposed if they make a wrong call and may add to re-work.

4.2. Engineering Specifications

Engineering specifications define the deliverables and set the performance and acceptance criteria for a contract. Engineering specifications may contain detailed descriptions of each deliverable or refer to industry benchmarks such as national and international standards, military specifications or other documentation.

As with engineering drawings both specifiers and fabricators must take care to ensure the engineering specifications are clear and understood at all levels.

Accuracy in fabrication is more difficult to achieve with production delays and possible rework as a result of misunderstanding of specification requirements.

5. Personnel

As with all endeavours where quality outcomes are paramount, having the right personnel is a prerequisite to achieving accuracy. Personnel must be trained, assessed for competency, have accountability for their actions and be proactive in initiating corrective actions.

5.1. Training

Achieving accuracy in fabrication requires an understanding of the many disciplines that influence accuracy. Training at all levels in the organisation is important to ensure personnel have an understanding of their roles and the impact of their particular activity on the accuracy of the finished product.

Ensuring appropriate training is provided is a management function.

5.2. Competency

Competency of personnel should be assessed on a regular basis to ensure training is adequate and procedures are being followed. This can be done at any time by peers and supervisors or by more formal means through an audit process.

Maintaining competencies of personnel, assessment of capabilities and deployment of appropriately skilled personnel is a management driven activity

5.3. Accountability

Most people take pride in their work and strive to achieve personal targets. There must be a means of measuring each activity that has an impact on the overall accuracy, with appropriate feedback to the individual responsible for that activity for accountability to be meaningful.

The feedback must be timely and the individual must have the training and competency to recognise a non-conformance and preferably the ability to determine the cause or causes of any non-conformances.

5.4. Corrective Actions

The processes to follow to initiate proactive correction of non-conformances must be clearly understood at all levels. Clearly boundaries must be set and authority levels established to ensure corrective actions do not adversely impact on other activities.

Continuous improvement is a concept that is now integral to most quality management systems

6. Quality Management

The terms Quality Management, Process Control and Quality Control are closely related. Quality management is a broad term to describe the management systems an organisation has in place to manage the quality of outcomes from their process and encompasses process control and in turn quality control. For a fabricator quality management involves all aspects of the fabrication task including: Contract review, Design review, Subcontractor, Welders, Welding coordination, Inspection personnel, Production equipment, Equipment maintenance, Production plan, Welding procedure specification (WPS), Welding procedure approval, Work instructions, Documentation, Batch testing of consumables, Storage and handling of welding consumables, Post-weld heat treatment, Inspection before, during, after welding, Non-conformances Procedures, Calibration Procedures, Identification, Quality records. (Refer AS/NZS ISO 3834).

Welding Coordination is the process of implementation of the quality management principles outlined above by allocation of specific tasks to individuals within the organisation and includes: Contract review, Design review, Materials, Welding consumables, Welding operations, Working environment, Health and safety, Weld procedures, Equipment, Fabrication Procedures, Inspection and testing, NDT, Assessment of inspection and testing results, Weld repairs, Acceptance, Documentation. (Refer ISO 14731).

7. Identifying Sources of Variation

In order to achieve overall accuracy in a fabrication all sources of variation must be identified. A holistic approach to the manufacturing process is required with integration of product and process knowledge. Identification of variation can be approached from the consideration of all the steps involved in design and manufacture that can have an impact on accuracy and putting process control measures in place to ensure conformance. Factors such as structural rigidity, material behaviour,

process limitations and operator dependency of some processes must be taken into account when allowing for shrinkage and distortion of welded components.

7.1. Drawings

Drawings in electronic format are increasingly being linked directly to marking out and cutting operations. This reduces the potential for errors and enables rapid feedback of systematic non-conformances in marking out and cutting to the engineering function. Minor changes to electronic drawings can be made to tailor the drawing to the manufacturing process or even individual production machines.

7.2. Precision in Marking Out and Cutting

Modern shipyards are utilising CAD/CAM in their laser and plasma cutting operations. The same equipment is now increasingly used for component identification and marking out. Marking out for subsequent assembly as part of the CAD/CAM cutting process minimises subsequent requirements for marking out, greatly reduces errors in marking out and improves assembly times.

This enables:

- High accuracy in cutting leading to good fit up in the fabrication shop, leading to less minor corrections and accompanying distortion.
- Identification of parts and marking out of cut pieces using dot matrix, laser or plasma systems. This leads to greatly enhanced traceability of parts, enhanced precision of assembly, thus minimising errors and rework.

7.3. Precision in Weld Preparation

Preparation of bevels for plate butt welds is now commonly by machining. While machining is more expensive than thermal cutting it enables compound bevels to be produced with precision not achievable by thermal cutting processes. Extremely accurate fitment of parts to be joined can be achieved. This is particularly important for larger welds such as main plate butt welds where major gains can be made in controlling overall distortion.

7.4. Precision in Assembly

This is where it all comes together and precision in assembly is dependent on accuracy of design, accuracy of cut parts, accuracy of marked assembly lines and last but not least the skills of the people doing the assembly.

7.5. Tack welding

Tack welding plays a critical role in firstly holding the assembled structure together ready for welding and secondly in maintaining correct root gaps in butt welds and preventing movement in the structure as welding progresses.

The number of tack welds, the length tack welds and the distance between them will depend on the length and thickness of the weld, the degree of rigidity needed, the details of the weld preparation and the welding process being used.

The tacking sequence can also have an effect and may need to be controlled to ensure correct root gaps are maintained along the length of a joint.

7.6. Back-To-Back Assembly

Back to back assembly of identical asymmetrical structures provides a method of counteracting the shrinkage forces of one component with the shrinkage forces of another. Additional presetting may be required so that when the two components are freed from each other there is no residual distortion due to spring back from locked up residual stresses.

7.7. Stiffening

Stiffening of a structure can be achieved in a number of ways. Use of larger tack welds, partially welding, provision of temporary bracing, use of assembly jigs with preset camber can be used to minimise distortion of a weldment. Longitudinal stiffeners welded along each side of a long seam can be used to prevent bowing of long members.

Stiffener location is important. If stiffeners are too far from the joint they are stiffening they may be ineffective, whereas if stiffeners are too close they may interfere with welding of the joint.

7.8. Pre-setting

Where a known amount of angular distortion will occur, presetting the joint by the amount of angular distortion expected ensures the alignment of the finished weld. This method can be very effective if consistent shrinkage rates are achieved through close control of welding procedures.

7.9. Jigs and Fixtures

Jigs and fixtures can be used for assembly and welding of subassemblies where the components are held rigidly until welded.

This approach works well for production of multiple smaller sub-assemblies.

7.10. Welding

7.10.1. Welding Process

Higher energy processes that allow higher welding speeds generally lead to lowering of shrinkage and distortion rates with the advantage of increased welding productivity. Implementation of processes enabling higher welding speeds may be difficult to justify solely on the basis of reduced welding time, but overall savings can be significant when the downstream costs of distortion correction are considered.

7.10.2. Controlled Welding Procedures

Ensuring all operators are following welding procedures ensures that weld metal shrinkage is consistent. Maintaining consistency in shrinkage outcomes requires good welding management systems. Welding procedures should be developed to ensure that minimal weld metal is deposited while maintaining the specified weld quality level.

When carrying out the fabrication it is important that the weld sizes are produced within the specified size range and weld shape is correct. Over-welding of thin structural sections is common although there is no advantage to the fabricator or customer in over-welding. On the other hand, undersize welds can lead to costly re-work with inevitable increased distortion.

7.10.3. Welding Technique

General rules for minimising distortion are:

- Keep weld volumes/size to the minimum specified
- Balance welds about neutral axes
- Keep the time between runs to a minimum
- Maintain preheat temperatures

7.10.4. Welding Sequence

The direction and sequence of welding is important in distortion control. Generally welds are made in the direction of free ends. For longer welds, back-step welding or skip welding is used.

- For back-step welding short weld lengths are placed with welding in the opposite direction to the general progression.
- For skip welding a sequence is worked out to minimise and balance out shrinkage stresses.

8. Shrinkage Prediction

Shrinkage at welds can be predicted with varying degrees of accuracy.

8.1. Shrinkage Prediction by Measurements

This is the traditional approach where a weldment is fabricated and the amount of shrinkage is measured. Dimensions of components can be increased to compensate for shrinkage. This approach may be impractical for larger, more complex weldments.

On complex components the overall shrinkage may vary considerably according to the assembly and welding sequence and the consistency of fit up and welding procedures.

8.2. Shrinkage Prediction by Modelling

Modelling is playing an increasingly important role in providing excellent first approximations of shrinkage as well as providing tools to assist in determining optimum assembly and welding sequences. To gain any real benefit from this approach there must be accuracy and consistency in all inputs to the model such as weld root gaps, weld preparations, welding procedures. Good process knowledge and subsequent process control are vital to the success of the model.

9. Shrinkage Compensation

Shrinkage compensation can be in the form of detail design changes enabled by management software or fabrication procedures.

9.1. Management Software

This includes software to assist in the design and planning of fabrications where compensation is made for predicted shrinkage.

9.2. Management Procedures

This includes techniques and practices implemented at the shop floor level where the collective wisdom of an organisation is embodied in procedures and practices that control and minimise shrinkage and distortion.

10. Summary

Some of the factors affecting the accuracy of welded fabrications have been identified. Adopting best practice principles can have significant cost benefits.

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NDNP TECHNOLOGY DIFFUSION ACTIVITY # 27	 Welding Technology Institute of Australia ABN 69 003 696 526	Document No: 9.4.3QR-0002
	NATIONAL DIFFUSION NETWORKS PROJECT TECHNOLOGY QUESTIONNAIRE Defence Industry Group “Accuracy control in shipbuilding”	Revision No: Rev 0
		Page 1 of 2 Date: 26 Apr 2006

As part of the WTIA National Diffusion Networks Project the Defence Industry Sector identified the need for guidance on improving accuracy in shipbuilding. The WTIA has prepared a Technical Guidance Note “Accuracy control in shipbuilding” to help understand the factors that control accuracy in welded ship fabrication and offer solutions to accuracy during the various stages of production. As a valued technology expert in this area we would like you to be part of the Technology Expert Group to review this note. Please complete this questionnaire so that we can gauge the success of meeting this need.

Objective 1: Identify the factors that influence fabrication accuracy

Ship designs are moving towards higher levels of design optimisation. This means thinner hull and frame plates and lighter stiffening members. Improved accuracy becomes crucial on such structures. This guidance note is intended to identify the significant parameters that can be managed to improve accuracy during the cutting, boilermaking, jiggling and welding processes. How well does the document explain how to improve accuracy?

poor average good very good

Comments: _____

Objective 2: Identify appropriate technology receptors in the Defence Industry

This document was written for Design and Production Engineers in the Defence Industry. Are these people the appropriate individuals we should be targeting?

yes no

What other types of companies and/or personnel do you suggest we target? _____

Objective 3: Identify best practice

The document was written to reflect current best practice and latest technology to improve accuracy. Do you envisage opportunities for the use of this technology in the industry?

yes no

If yes, what and where, if no why not? _____

Objective 4: Is the information provided clear, concise and accurate?

yes no

If not, why? _____

Objective 5: Broad dissemination of technology to the Defence Industry

Please indicate how best to disseminate this Technical Guidance Note to the appropriate Defence Industry Recipients

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If poster, what size? A1 A2 A3 Laminated What selling price? \$

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Objective 6: Continuous Improvement

Please Identify areas where the document can be improved or return the document with your recommended additions/amendments. Alternatively, please use the area below to provide any additional comments.

Respondents Name: _____ *Company:* _____ *Phone:* _____

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Please Fax (02 9748 2858) or E-mail (info@wtia.com.au) your response.

The WTIA has joined forces with industry and government to create a 3.5 million dollar Technology Support Centres Network. This network will assist industry to identify and exploit world's best technology and manufacturing methods to establish a vibrant Australian industry beyond 2006. Together we will be implementing a step by step process which will lead to ongoing viability and greater profitability for all concerned:



- (1) Determine your technological and manufacturing needs;
- (2) Identify world's best practice;
- (3) Draw upon the network to implement world's best practice at your site

