1. Objective

The objective of the guidance note is to identify the factors that must be considered in controlling preparation of plates for use in welded ship fabrication. 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 welded plates, bulkheads, stiffeners and many smaller components cut from plate. Controlling plate preparation is an essential part of the process of minimising distortion and maintaining accuracy in fabrication, hence it is critical to the success of modern shipbuilding. The current trend to optimised designs using thinner plates and lighter stiffening creates greater challenges in plate preparation.

3. Factors Affecting Cut Quality

The precision or dimensional accuracy of a cut is important as it helps to ensure correct part tolerances and fit-up, thus eliminating rework or secondary processing operations further down the production line. The main criteria used to assess the quality of a cut are as follows.

3.1. Kerf

Kerf is defined as the width of the cut at its widest point. The kerf gives an indication of the minimum internal radius or feature that can be cut.

3.2. Cut Edge Roughness, Rz,mm

Cut edge roughness is used to define the cosmetic appearance of a cut and can give an indication of whether subsequent machining operations are necessary. Cut edge roughness is determined by an Rz value in microns (also known as the ISO 10 point height parameter). This is a measure of the surface roughness transverse to the cut edge produced by traversing at 2/3 depth with a stylus and taking an average value.

3.3. Cut edge Squareness, U

Cut edge squareness is defined in terms of the Perpendicularity and Angularity tolerance, U (mm). This is a measure, in millimetres, of how much the cut edge deviates from a perfect square edge. Edge squareness affects the fit-up between two components and determines whether any post cutting machining operations will be necessary.

3.4. Heat Affected Zone (HAZ) Width

HAZ width is defined as the width of a detectable microstructural change measured perpendicular to the cut edge face. HAZ width is only applicable to alloys that undergo microstructural changes during the heating and cooling cycle of the cutting operation, i.e. alloys that are hardenable or heat treatable. The width and properties of the HAZ are important due to the potential for local degradation and the possibility of the need for removal of this material before final assembly of the product.

3.5. Dross

Dross is defined as the resolidified material that adheres to the bottom edge of a cut produced by a thermal process. Levels of dross are quantified subjectively, with the terms none, light, medium and heavy commonly used.

3.6. Thermal Distortion

Thermal cutting processes inevitably induce localised expansion and contraction exceeding yield point strains. The degree of thermal distortion is related to both the heat input of the cutting process and the physical and mechanical properties of the material being cut. Lowest distortion is achieved with lower heat input processes or cold cutting processes such as machining and abrasive water jet cutting.

4. Plate Surface Preparation and Protection

4.1. Carbon Steel Plates

Accuracy and consistency of cutting is greatly enhanced by removal of scale and oxides from carbon steel plates. Plates are usually supplied in the blasted and primed condition or blasting and priming are the first steps in the fabrication process. Coatings used are thinly applied weld through primers for the purpose of protection of the plate surface during the fabrication process.

Higher cutting speeds, higher precision in cutting and lower distortion are direct benefits of using blasted and primed plate.

4.2. Aluminium Plates

Aluminium plates require no preparation for cutting. Care must be taken in storage to prevent water damage or contamination of surfaces.

5. Accuracy of Design

Designers have the opportunity to play a key role in ensuring the success of large and complex fabrications. Today's designers have access to more precise information and more consistent and determinate inputs to accurately incorporate allowances for sources of variation in the fabrication process. There is more pressure on designers to get the details correct, but the payoff is greater opportunity for mechanisation, which in turn leads to enhanced precision and efficiency of production.

A key cost saving area can be the elimination or minimisation of extra process steps such as trimming off excess material on parts and assemblies just prior to integration into larger pieces. To capitalise on this vital area the designer must have a fundamental understanding of the issues facing the fabricator including cutting kerf, post cut dressing, distortion from cutting, required joint gaps, weld zone shrinkage and variations in material properties and welding heat input. The process is further enhanced by constant communication between the designer and fabricator to "fine-tune" the design.

6. Marking Out Plates for Cutting

Wherever practicable, there is no marking out for cutting in modern shipyards. Shipyards are utilising CAD/CAM in their cutting operations and the same equipment is now increasingly used for component identification and marking out. Cutting information is transferred directly from the design package to the cutting equipment. The current trend is to use the cutting equipment to complete as much marking of mounting lines, bending lines and transcribing of part identification information as possible. The marking out process is completed on the cutting bed before cutting is started. This approach eliminates translational or interpretation errors by the direct transfer of the cutting information from the drawing package to the cutting equipment, which greatly reduces errors in marking out and improves assembly times.

Identification of parts and marking out of cut pieces may be accomplished with dot matrix, laser or plasma systems. This leads to greatly enhanced traceability of parts, enhanced precision of assembly, minimising errors and rework.

7. Plate Cutting and Bevelling

High accuracy in cutting leads to good fit up in the fabrication shop, with less minor corrections and accompanying distortion. Plates may be cut by a variety of processes and the advantages and limitations of each process are briefly described.

7.1. Oxy-fuel gas (flame) cutting

Oxy-fuel gas is still the most widely used process for cutting steel plates. It can be used to cut thicknesses from 0.5mm to 2,500mm. LPG or acetylene fuel gases are used with LPG preferred in most instances.

The equipment is low cost and can be used manually or mechanised. There are several fuel gas and nozzle design options that can significantly enhance performance in terms of cut quality and cutting speed.

7.1.1. Choice of Fuel Gas

The five most commonly used fuel gases are acetylene, propane, MAPP (methylacetylene-propadiene), propylene and natural gas. The properties of the gases are given in the Table 2. The relative performance of the fuel gases in terms of pierce time, cutting speed and cut edge quality, is determined by the flame temperature and heat distribution within the inner and out flame cones.

Whilst pierce times are higher for propane, the cutting speeds are about the same as for acetylene.

7.1.2. Oxygen Purity

The purity of oxygen should be at least 99.5%. A decrease in purity of 1% will typically reduce the cutting speed by 25% and increase the gas consumption by 25%.

Oxygen stream purity is a critical factor in achieving high cutting speeds and good edge quality. Good nozzle design and maintenance of nozzle condition plays a significant role in protecting the oxygen stream from air entrainment.

7.1.3. Plate Surface Condition

It is good practice to dress oxides from surfaces to be welded.

7.2. Plasma Cutting

The plasma process operates by using the arc to melt the metal so it can be applied to cutting metals, which form refractory oxides such as stainless steel, aluminium, cast iron and non-ferrous alloys.

The process differs from the oxy-fuel process in that the plasma process operates by using the arc to melt the metal whereas in the oxy-fuel process, the oxygen oxidises the metal and the heat from the exothermic reaction melts the metal. Thus, unlike the oxy-fuel process, the plasma process can be applied to cutting metals that form refractory oxides such as stainless steel, aluminium, cast iron and non-ferrous alloys.

7.2.1. Cut Quality

The quality of the plasma cut edge is similar to that achieved with the oxy-fuel process. However, as the plasma process cuts by melting, a characteristic feature is the greater degree of melting towards the top of the metal resulting in top edge rounding, poor edge squareness or a bevel on the cut edge. As these limitations are associated with the degree of constriction of the arc, several torch designs are available to improve arc constriction to produce more uniform heating at the top and bottom of the cut.

7.2.2. Advantages and Limitations

Plasma cutting offers advantages over oxy-fuel gas cutting with the major advantages being cutting speed, cleanliness of the cut and reduced thermal distortion.

Plasma cutting is the most widely used process for cutting of aluminium and stainless steel components.

In some instances plasma cut surfaces in carbon steel may be welded without dressing but it is good practice to dress surfaces. It is always necessary to dress oxides from plasma cut surfaces in aluminium and stainless steel.

Plasma cutting is more expensive to implement than oxy-fuel gas cutting.

7.2.3. Process Variants

Process variants been developed to improve cut quality and arc stability, reduce the noise and fume or to increase cutting speed.

- **Dual Gas** - The process operates basically in the same manner as the conventional system but a secondary gas shield is introduced around the nozzle. The beneficial effects of the secondary gas are increased arc constriction and more effective 'blowing away' of the dross. The plasma forming gas is normally argon, argon-H2 or nitrogen and the secondary gas is selected according to the metal being cut.
    - Steel – air, oxygen, nitrogen
    - Stainless steel – nitrogen, argon-H2, CO2
    - Aluminium – argon-H2, nitrogen / CO2

  The advantages compared with conventional plasma are:
    - Reduced risk of 'double arcing'
    - Higher cutting speeds
    - Reduction in top edge rounding

- **Water injection** - Nitrogen is normally used as the plasma gas. Water is injected radially into the plasma arc, to induce a greater degree of constriction. The temperature is also considerably increased, to as high as 30,000°C.

  The advantages compared with conventional plasma are:

  - Improvement in cut quality and squareness of cut
  - Increased cutting speeds
  - Less risk of 'double arcing'
  - Reduction in nozzle erosion

- **Water shroud -** The plasma can be operated either with a water shroud, or even with the workpiece submerged some 50 to 75mm below the surface of the water. Compared with conventional plasma, the water acts as a barrier to provide the following advantages:

  - Fume reduction
  - Reduction in noise levels
  - Improved nozzle life

  In a typical example of noise levels at high current levels of 115dB for conventional plasma, a water shroud was effective in reducing the noise level to about 96dB and cutting under water down to 52 to 85dB.

  As the water shroud does not increase the degree of constriction, squareness of the cut edge and the cutting speed are not noticeably improved.

- **Air plasma** - The inert or unreactive plasma forming gas (argon or nitrogen) can be replaced with air but this requires a special electrode of hafnium or zirconium mounted in a copper holder. The air can also replace water for cooling the torch. The advantage of an air plasma torch is that it uses air instead of expensive gases.

  It should be noted that although the electrode and nozzle are the only consumables, hafnium tipped electrodes could be expensive compared with tungsten electrodes.

- **High tolerance plasma** - In an attempt to improve cut quality and to compete with the superior cut quality of laser systems, High Tolerance Plasma Arc cutting (HTPAC) systems are available which operate with a highly constricted plasma. Focusing of the plasma is effected by forcing the oxygen generated plasma to swirl as it enters the plasma orifice and a secondary flow of gas is injected downstream of the plasma nozzle. Some systems have a separate magnetic field surrounding the arc. This stabilises the plasma jet by maintaining the rotation induced by the swirling gas. The advantages of HTPAC systems are:

  - Cut quality lies between a conventional plasma arc cut and laser beam cut
  - Narrow kerf width
  - Less distortion due to smaller heat affected zone

  HTPAC is a mechanised technique requiring precision, high-speed equipment. The main disadvantages are that the maximum thickness is limited to about 6mm and the cutting speed is generally lower than conventional plasma processes and approximately 60 to 80% the speed of laser cutting.

7.3. Laser cutting

In this thermal cutting process, a water-cooled lens focuses a laser beam to a very fine spot (<0.5mm) with a very high power density (>10^5 W/mm^2). The focussed laser beam impinges on the surface of the workpiece with sufficient power density to melt or even partially vaporise most materials. Once a through thickness zone of molten or vaporised material is generated (a keyhole), a jet of assist gas, delivered co-axially through the cutting nozzle, is used to eject this material from the kerf. The resulting cutting kerf is surrounded by molten material, which is continuously ejected during the cutting process by a stream of cutting gas.

There are two commonly used types of industrial cutting laser, CO_2 and Nd:YAG. These differ in that the wavelength of infrared light produced is 10.6μm for CO_2 lasers and 1.06μm for Nd:YAG lasers. Both these types of lasers produce the cut by focusing a beam of monochromatic light to a very small spot size by lenses and mirrors. The shorter wavelength of the Nd:YAG laser enables the light to be transmitted to the workpiece by fibre optics allowing three dimensional cutting or trimming of parts.

Light from CO_2 lasers is transmitted to the workpiece by mirrors or transmissive optics. Although three dimensional cutting systems are available for CO_2 lasers they are relatively cumbersome compared to fibre delivered Nd:YAG lasers. CO_2 lasers are more commonly used for two dimensional flat bed cutting.

7.3.1. Cut quality

Laser-cut edges are typically very square and the process is capable of cutting at very high speeds. The combination of a very high energy, concentrated heat source moving at high speeds results in very little heat being transmitted to the surrounding material (low heat input) so there is very little thermal distortion of parts.

- Kerf - Laser cuts possess a narrow to very narrow kerf width (0.5-1.0mm) for CO_2 and Nd:YAG lasers respectively.
- Cut edge roughness, Rz,mm - Both CO_2 and Nd:YAG processes produce cuts with a low edge roughness (<50µm).
- Cut edge squareness, U - CO_2 and Nd:YAG lasers are capable of producing cuts with good edge squareness (<0.5mm).
- Heat Affected Zone (HAZ) width - The concentrated heat source produced by both CO_2 and Nd:YAG lasers produces a very narrow HAZ (<0.5mm).
- Dross - For laser cutting, dross is light provided the cutting parameters are optimised.

7.3.2. Economics of laser cutting processes

Whilst most suited for precision cutting of thin sheet in the 1 to 15mm thickness range, both CO_2 and Nd:YAG laser cutting systems require high capital investment with the more expensive higher power units required for thicker plates or higher cutting speeds. Precision work handling equipment is required if a laser is to be used to its full potential, in terms of cutting speed and quality.

As a result, laser cutting systems typically are used where high cut quality requirements make their application essential, or where the initial investment is offset by the high production rates that can be reached as a result of their high cutting speeds on thin sheet materials

Laser cutting offers a high precision, CNC controlled method of cutting a wide range of materials including plastic, metallic and thin ceramic components. It is a mechanised, thermal, non-contact process capable of cutting most materials with a high degree of precision and accuracy with minimal distortion and residual stress.

The thickness of material that can be cut is limited by the power of the laser. Refer Table 1 for typical material thicknesses.

Laser cutting centres have been set up that provide cutting services for many fabricators. This approach ensures high utilisation of the equipment and offsets the high capital investment.

7.4. Air-Arc

An arc cutting process in which the metals to be cut are melted by the heat of the carbon arc and a stream of high-pressure air blows the molten metal away. This process is used for back gouging but rarely for initial edge preparation.

7.5. Oxy-Arc

An oxygen cutting process in which the necessary cutting temperature is maintained by means of an arc between an electrode and the base metal. This process is primarily used for underwater cutting.

8. Edge Preparation Methods

Weld preparations can be made on plate edges by a variety of processes and the advantages and limitations of each process are briefly described.

8.1. Machining

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.

8.1.1. Milling

Plate edges can be prepared by milling to produce compound bevels of consistent form with high accuracy of fit-up.

Milling of long plate edges is cost effective when high volumes are required and higher energy welding processes are used.

8.1.2. Router Cutting

Router cutting is widely used for preparation of square edges on aluminium. Router cutting may be used for initial cutting or as a means of cleaning up and preparing the edge for welding following plasma cutting.

Refer Table 1

8.2. Oxy-Fuel Gas Cutting

Oxy-fuel gas cutting is used on thicker steel components to produce bevels. Surface oxides from oxy-fuel gas cutting must be removed by a process such as grinding before welding.

8.3. Plasma Cutting

Plasma cutting is a better alternative than oxy-fuel gas cutting offering higher speeds, higher accuracy and less distortion. Surface oxides are lighter than for oxy-fuel gas cutting may still have to be removed before welding

8.4. Laser Cutting

Laser cutting offers very high precision in preparation with virtually no distortion. Surface oxides are generally minimal and dressing before welding.

9. Selection of Cutting Process

Selecting the most suitable cutting process can be complex because there are many factors that must be considered. There may be several processes that could be suitable for a particular application, however the final choice usually depends on capability to economically produce the required quality. Factors to consider may include:

- Type of material
- Range of thickness
- Quality of cut required
- Complexity of components
- Accuracy of the cutting process
- Number of components to be cut
- Allowable distortion from the cutting process
- Sub-contract or in-house production of cut components
- Secondary operations such as bevelling or removal of HAZ or oxides from cutting

Assessment of these factors will usually reduce the number of potential cutting processes down to two or three which are likely to satisfy general requirements.

Information is available to compare relative costs of different cutting processes but the actual values will vary depending on the specific application, equipment used, as well as geographical location.

10. Work Handling

Work handling describes how the cutting head (or tool) and workpiece are moved relative to one another and the way in which this is achieved.

The two most common ways of obtaining relative motion between the cutting head (or tool) and workpiece are:

- Workpiece remains stationary while cutting head moves
- Workpiece moves relative to stationary cutting head

Some laser cutting systems employ both the above, simultaneously. This relative motion can be achieved using one of the following human or mechanical means:

- Hand held (only applicable to some processes)

- Mechanical linear (1-D)
- Mechanical x-y traverse (2-D)
- Mechanical 3-D robot
- Gantry type 5-axis system for 3-D processing

Sophisticated systems for cutting utilise machine tool technologies. From a CAD drawing of the component, some systems are able to calculate the required path, allowing for kerf widths, and even program cutting parameters, to produce consistent edge quality. Table 1.2 indicates the type of work handling system used for cutting processes covered by the guide. 'SW' indicates a stationary workpiece, while 'MW' indicates a moving workpiece. In general, when processing heavy workpieces, it is usual for the workpiece to remain stationary; when processing very fine detail, it is common for the workpiece to move.

11. Summary

Control of plate preparation has been outlined with guidance on

- Factors Affecting Cut Quality
- Plate Surface Preparation and Protection
- Accuracy of Design
- Marking Out Plates for Cutting
- Plate Cutting and Bevelling
- Edge Preparation Methods
- Selection of Cutting Process
- Work Handling

12. Acknowledgements

A significant amount of information used in the production of this guidance note was obtained from the TWI website. For additional information refer www.twi.co.uk.

Table 1 Applicability and maximum thickness (mm) that can be cut by the main cutting processes

	Oxy-fuel Gas (Flame)	Plasma Arc	High Tolerance Plasma Arc	Laser CO_2	Laser Nd:YAG	Air-Arc	Oxy-Arc
C-Mn Steel	500	90	13	20	10	50	75
Stainless steel	✗	90	13	12	10	50	50
Armour steel	✗	90	10	18	10	50	50
Al + alloys	✗	150	13	10	5	50	50
Cu + alloys	✗	60	13	✗	5	50	50
Ni + alloys	✗	75	13	10	10	50	50
Ti + alloys	300	75	13	10	10	50	50

Notes

✗ not suitable

Mechanical methods, such as sawing and milling, can be used successfully on any of the materials given in the *Table*.

Table 2: Fuel Gas Characteristics

Fuel Gas	Maximum Flame Temperature °C	Oxygen to Fuel Gas Ratio (vol)	Heat Distribution kJ/m_3	
			Primary	Secondary
Acetylene	3,160	1.2:1	18,890	35,882
Propane	2,810	4.3:1	10,433	85,325
MAPP	2,927	3.3:1	15,445	56,431
Propylene	2,872	3.7:1	16,000	72,000
Natural Gas	2,770	1.8:1	1,490	35,770

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NDNP TECHNOLOGY DIFFUSION ACTIVITY # 27	ABN 69 003 696 526 **NATIONAL DIFFUSION NETWORKS PROJECT** **TECHNOLOGY QUESTIONNAIRE** **Defence Industry Group** **"Control of plate preparation"**	**Document No:** 9.4.3QR-000X **Revision No:** Rev 0 **Page 1 of 2** **Date:** 30 May 2006

As part of the WTIA National Diffusion Networks Project the Defence Industry Sector identified the need for guidance on the control of plate preparation in shipbuilding. The WTIA has prepared a Technical Guidance Note "Control of plate preparation" to help understand factors affecting plate preparation and offer solutions to achieve appropriate levels of control. 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, and offer solutions to achieve control of plate preparation

Modern shipbuilding involves the fabrication of large and complex welded structures in blocks with high levels of fit-out completed, including piping and other services within each block, requiring a high degree of dimensional accuracy to enable efficient integration into the structure. The current trend to optimised designs using thinner plates and lighter stiffening creates greater challenges in control of plate preparation, which is a vital part of overall accuracy control. This guidance note is intended to identify the factors influencing plate preparation in the fabrication of welded ships and offer solutions to achieve the required levels of control. How well does the document explain the critical factors and solutions to achieve control of plate preparation required?

poor ☐ average ☐ good ☐ very good ☐

Comments: ____________________

Objective 2: Identify appropriate technology receptors in the Defence Industry

This document was written for Designers, Fabricators and Maintenance practitioners 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 for control of plate preparation. 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

Free Website Download ☐ Poster☐ Pocket Guide ☐ Pamphlet ☐

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

If a pocket guide, what selling price? $

Other format? ____________________

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.

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Please Fax (02 9748 2858) or E-mail (b.gross@wtia.com.au) your response. Your prompt response is appreciated.

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