A DESIGN METHODOLOGY FOR WELDED STRUCTURES TO BE USED ON U.S. NAVY SURFACE COMBATANT SHIPS

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(ABSTRACT)

The objective of this work is to integrate manufacturing considerations of arc welding processes in the early stages of welded structures design. This is accomplished through the development of a framework that allows design engineers to investigate the appropriate trade-offs between deposition rates, operator factors, deposition efficiency, welding position, accessibility, weldability, and joint design at an early stage in the design. The impact of different decision making alternatives made early in the product life cycle are supported by expected costs. The system details are demonstrated with the major welding processes and hull non-nuclear steels used in the construction of surface combatant ships in the United States Navy.

ACKNOWLEDGMENTS

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Chapter 1

INTRODUCTION

Arc welding is the most widely used process for joining large structures, such as ships. Welding offers many advantages over riveting. In addition to punching and drilling costs, riveted joints usually require one or two gusset plates (see Figure 1). Thus, welding reduces the weight of the structure and fabrication time over riveting. Welding is also more adaptable to irregular shapes, and thus provides designers with added design flexibility. Welding is a quieter operation and can be used anywhere. However, a limitation of welding is that some weld joints require internal inspection and the results must be interpreted by someone knowledgeable in the field of nondestructive testing (NDT). Nevertheless, riveting operations are rarely used today in joining large structures [1, p.1].

Many advances have occurred over the past decade in arc welding processes. In the past, the manual shielded metal-arc welding process with its low operator factor, deposition rate and filler metal utilization was the primary welding process used in the construction of large structures. Today, semi-automatic and automatic methods of

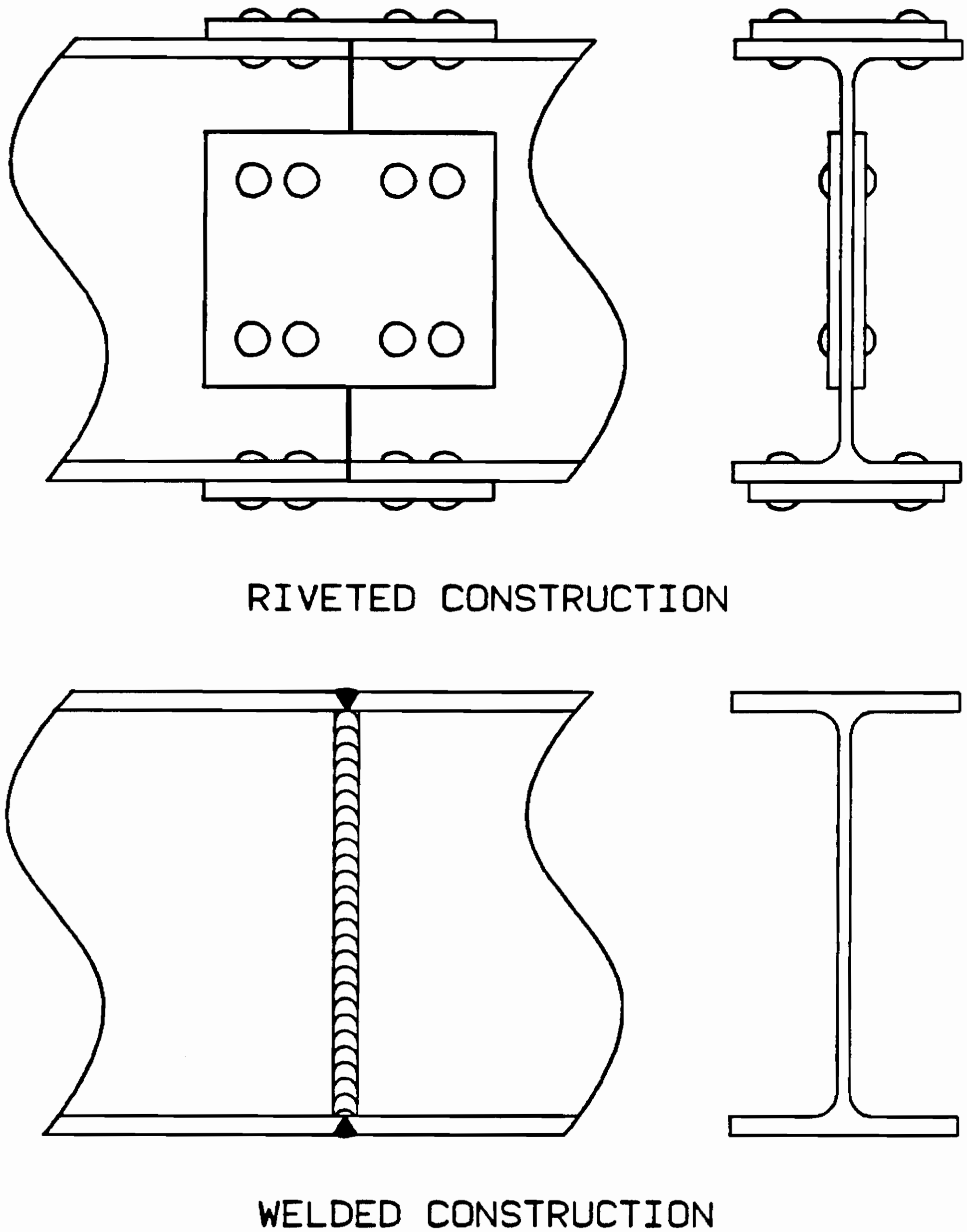


Figure 1. Comparison of Riveted and Welded Construction for a Splice in a Wide Flange Member [1, p.2].

gas metal-arc welding, submerged arc welding, and flux-cored arc welding processes are increasingly replacing the shielded metal-arc welding process. Characteristics of the semi-automatic and automatic methods are higher operator factor, deposition rate and filler metal utilization. Also, smaller electrode diameters can be utilized to allow for greater penetration. However, to achieve maximum efficiency for the automated welding methods, a different standard for weld joint details will be needed. The current standard is based only on the process capabilities of the shielded metal-arc welding process [2]. Typical benefits from integrating manufacturing considerations regarding automated welding processes early in the design process include smaller fillet sizes and reduced included angle of bevel for groove welds. This, in turn, results in less filler metal deposited and thus cost reduction.

Although a product's design cost is around 5% of the total cost, the design usually determines more than 70% of the manufacturing costs [3]. By the time a product design reaches the manufacturing engineer, he/she has at best 30% of the product cost to optimize. This is, in part, due to the sequential process of design and manufacturing decisions making. New management concepts such as concurrent or simultaneous engineering which aim at integrating design and manufacturing activities early in the design process are currently under implementation in several installations to overcome this sequential decision making problem [3]. However, the majority of these attempts are mainly concerned with the creation and management of teams made of design and manufacturing engineers. The objective of this work is to develop a framework which automatically integrates design and manufacturing considerations regarding weld structures early in the product life cycle.

The majority of the published work on large structure welding can be grouped under welding designs or welding processes. Research work on welding designs is usually concerned with weld joint geometry in relation to forces, stresses and weld quality [4,5,6]. On the other hand research work dealing with welding processes is usually concerned with developing, optimizing and/or comparing welding processes [7,8,9]. Although two computer-aided literature surveys were run and resulted in 79 papers on the subject of weld structures, a research work dealing with how manufacturing considerations can be integrated early in the design process for selecting a welding process that optimizes the total cost was not found.

The objective of this work is, therefore, to develop a framework that integrates design and manufacturing considerations for the optimal selection of a welding process early in the design cycle of welded structures. The developed methodology allows design engineers to investigate appropriate trade-offs between joint design, material weldability, welding position and accessibility, deposition rate and efficiency, and operator factors during the design process. The impact of different decision making alternatives made early in the design are supported by expected costs. The system details are based on the major welding processes and hull non-nuclear steels utilized in the construction of surface combatant ships in the U.S. Navy.

The layout of this report is as follows: chapter 2 provides the related literature review, chapters 3 and 4 provide background information on design considerations and welding processes capabilities for welded structures, chapter 5 presents the developed methodology along with examples based on the hull non-nuclear structure of United States Navy surface combatant ships, and chapter 6 outlines the conclusions and future works.

CHAPTER 2

LITERATURE REVIEW

Two 'weldasearches', online computer searches, were done by the Edison Welding Institute of Columbus, Ohio for this project. Based on keywords such as economics, shipbuilding, welded joints, weldability, joint/design, and construction, 79 papers were located by the two searches. Additionally, literary researches were conducted at three universities. A previous work on how to integrate manufacturing considerations in the design process for welded structures was not found. Nonetheless, these literary searches coupled with other industry reference information resulted in some work pertinent to this research project and is discussed herein.

Lucas [4] presented a designer's guide for welding low carbon steel structures. He investigated the impact of static, fatigue, and impact loadings on the base metal, weld metal, and weld heat-affected zones. He recommended that the designer should analyze stresses in the structure, and design for a given welding process and weld metal. However, he did not address how the designer would select a given welding process and weld metal. Also, important factors such as the welding position which directly impacts the welding process efficiency or the use of automation were not considered.

Howden [5] discussed the cost-effectiveness of welding metals in terms of weld joint geometry, material, and weld type. He pointed out that design engineers must not only consider design and material requirements but should also consider manufacturing aspects, such as machining and welding processes. However, he did not provide a framework for incorporating this information into the design cycle.

Cameron [7] provided an overview of welding costs in shipbuilding. Cost factors such as weld deposition rate, operator factor, joint design, fit-up tolerance, allowable energy input, direct labor cost and overhead, and consumable material were considered. Although Cameron's graphs and tables relating the factors to labor cost were given, he did not address how and when these factors can be utilized in the design process. Also, other important factors such as weld joint accessibility and material weldability which can limit some welding processes were not addressed.

Carter [9] discussed the benefits and limitations of advanced welding technology. Typical benefits include higher productivity/lower unit cost, high quality/lower defect rates, and better control of distortion. Possible limitations are development costs and the lack of flexibility in the operation. However, incorporating this information in the design cycle was not addressed.

Although none of the above references addressed how manufacturing considerations can be integrated early in the design process for selecting a welding process for a given welded structure, their work indirectly contributed to this research project, the development of a design methodology for welded structures.

Chapter 3

DESIGN OF WELDED STRUCTURES

In designing a ship welded structure, design engineers attempt to satisfy economic, aesthetic, and functional requirements. The structure, subject to load-carrying performance requirements, is analyzed to efficiently design decks, bulkheads, foundations, etc. Expected service conditions are considered so that the designed structure can survive in a given environment. Appropriate metals are selected based on the stress analysis results. Steels with higher strength than the analysis results are usually selected to reduce ship weight. Weld joints are then selected or designed to properly carry the loads and sustain the required service life of each weldment. There are several factors that a design engineer must consider in determining welded joint designs for Navy shipbuilding. This chapter describes these factors.

3.1 LOAD CONDITIONS AND SERVICE REQUIREMENTS

The United States Navy requires their ship structures to be designed for the most severe combinations of loads. A load is defined as an external force acting on a structure.

Loads are usually a function of time, area, and location/method of application.

Static, impact, or repeated loads are all considered as a function of time. Static loads are forces that are applied slowly and then remain nearly constant. Static loads can be the weight or dead load of a structure bearing on another one. Impact loads significantly vary with time; an example of which is a falling weight striking a deck or the shock wave from an explosion stressing a bulkhead. Repeated loads also vary with time and usually result from machinery such as pumps which oscillate and create alternating forces.

Loads can be also classified as concentrated or distributed. Concentrated loads are forces that act on a small contact area, negligible when compared with the entire surface area of the supporting member. A distributed load is a uniformly or nonuniformly distributed force acting over the whole surface of a supporting member. Figure 2 illustrates both concentrated and distributed loads. Figure 3 shows the outcomes of different load applications. The design engineer may consider a combination of these load applications.

Figure 2. Diagrams of Concentrated and Distributed Loads.

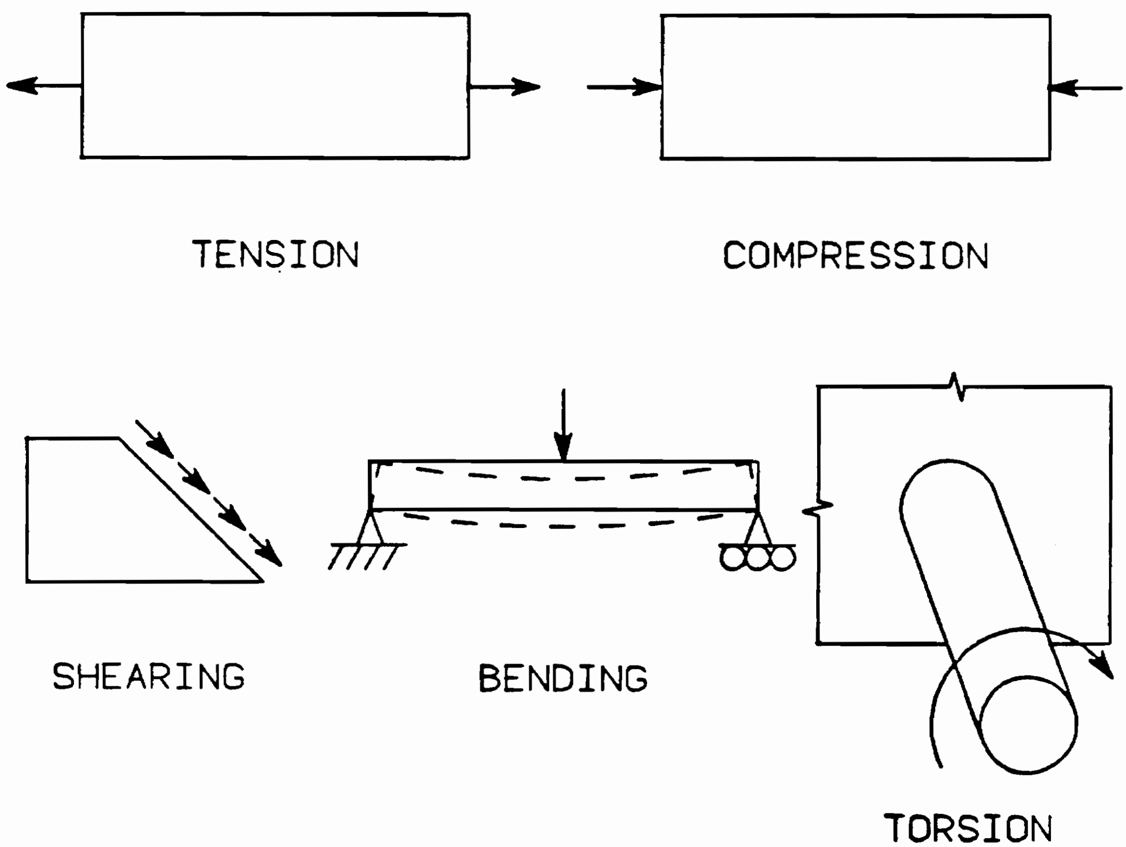


Figure 3. Diagrams of Tension, Compression, Shearing, Bending and Torsion Loads.

A Naval ship structure in a combatant environment must be able to withstand shock loads produced by an underwater explosion. Since water is an efficient transmitting medium, and with the development of nuclear weapons with its potential for detonating underwater, a shock load can damage ship structure from many miles away. Furthermore, a surface burst of a nuclear explosion will produce a blast wave potentially damaging to a structure exposed on the topside of the ship. The nuclear airblast induces shock in the ship's structure which can be equally damaging.

In the event that a ship is damaged, loads in the form of flooding or hydrostatic head need to be considered to ensure principle watertightness of ship structure. Other loads include storm condition wind loading which could be loads on aircraft on flight deck transferred to the ship structure through tie-downs. The live loads of landing and catapulting stress the flight deck and all supporting structures. The ship also acts as a giant beam hogging and sagging many cycles per day. Hogging is the straining of the ship that tends to make the bow and stern lower than the middle portion. Sagging is the straining of the ship that tends to make the middle portion lower than the bow or stern.

These loads and others must be determined and analyzed by the design engineer to efficiently design a ship structure with the most economical materials.

3.2 STEEL SELECTION

The major steels used in the construction of a hull structure for surface combatant ships in U.S. Navy are mild steels (MS), high tensile steels (HTS), and the alloy quenched and tempered steels of HY80 and HY100. The mild and high tensile steels are available in plates and shapes, and the U.S. Navy requires the Mil-Std-22698 specification [12] to be used. The HY100 and HY80 steels are mainly available in plates, and the U.S. Navy requires the Mil-Std-16216 specification [13] to be used.

The design engineer selects a steel grade based on its capabilities to resist fracture under normal load and service conditions. Some of the properties a design engineer will investigate before the final selection of a steel grade are the ultimate strength, yield strength, ductility, compressive strength, shear strength, and fatigue strength. Compressive strength may vary based on the geometry of the steel member. Short members tend to have a higher compressive strength than its ultimate tensile strength. Shear strength has no recognized standard of testing. It is generally assumed that the ultimate shear strength is 75% of the ultimate tensile strength. The endurance limit is a measure of the material's fatigue strength. The member geometry and location of stress concentrations must be considered for a more reliable information on the fatigue strength of a member [14, p.2.1-1].

Steels with high strength can reduce the weight of a ship. However, steels with high strength usually have high carbon content. A carbon content above 0.45% may result in poor weldability [15, p.180].

3.3 WELD JOINTS

The selection of a weld joint type depends on the type of loads applied. A weld joint is a combination of a joint and weld type. There are five basic types of joints as shown in Figure 4: (1) Butt, (2) Corner, (3) Tee, (4) Lap and (5) Edge. A butt is a joint between two members approximately in the same plane. A corner is a joint between two members located approximately at right angles to each other in the form of an L. A tee is a joint between two

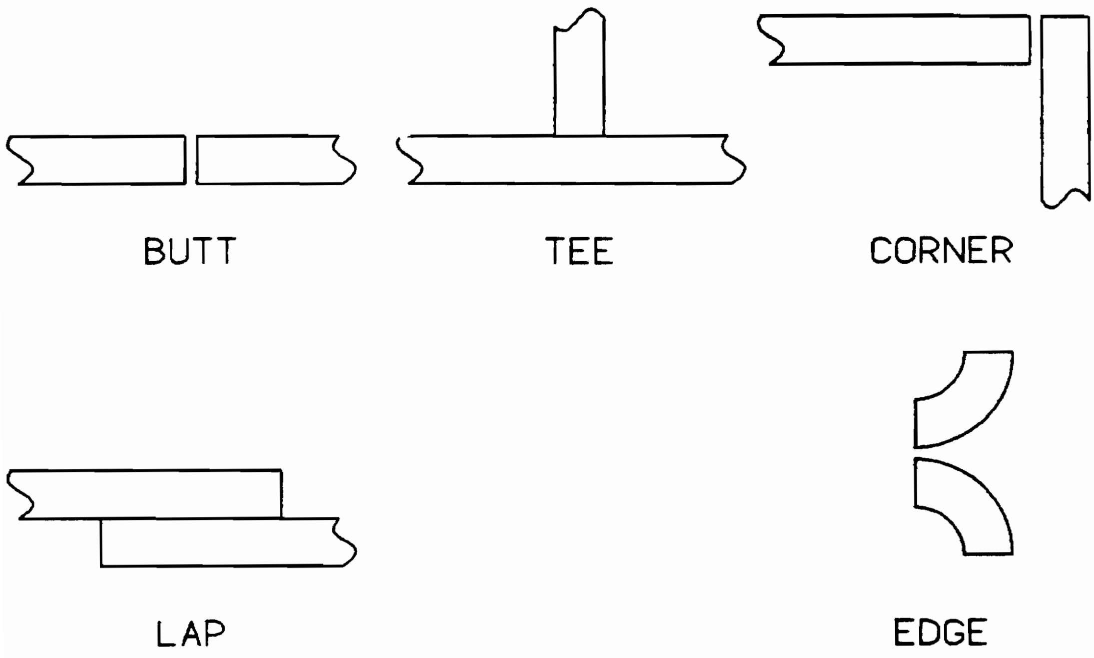


Figure 4. Diagrams of Joint Types.

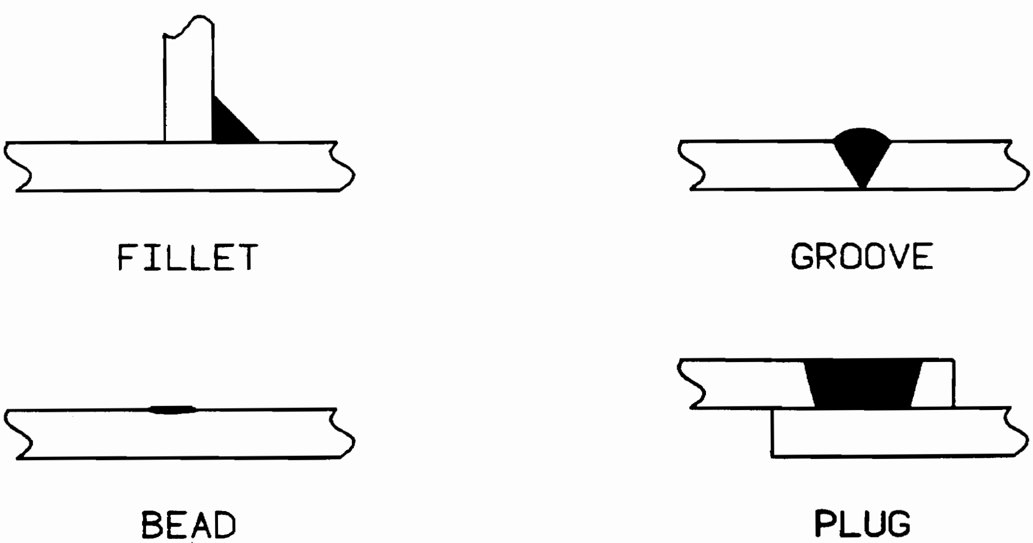


Figure 5. Diagrams of Weld Types.

members located approximately at right angles to each other in the form of a T. A lap is a joint between two overlapping members. An edge is a joint between the edges of two or more parallel or nearly parallel members.

The most common weld types as shown in Figure 5 are (1) Fillet, (2) Groove, (3) Bead, and (4) Plug. A fillet weld is approximately a triangular cross-section and is used for joining two surfaces approximately at right angles to each other, such as a lap, tee, or corner joint. A groove weld is a weld made in a groove between two members to be joined. A bead weld is composed of one or more stringer or weave beads deposited on an unbroken surface to obtain desired properties or dimension. A plug is a circular weld made through a hole in one member of a lap joint.

The U.S. Government requires the Mil-Std-22 specification [2] to be used for the construction of U.S. Navy ships. It provides the design engineer with weld joint designs, limitations, areas of application, and welding symbols. All the joint designs in this military specification are prequalified for the shielded metal-arc welding, gas metal-arc welding, submerged arc welding, and flux-cored arc welding processes. However, modifications can be made to the joint design to take better advantages of a given process capability provided that the U.S. Navy approval is granted.

3.4 WELD JOINT DESIGN

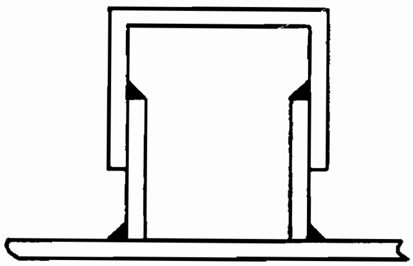
Typical factors considered in the design of a welded joint are (1) load and service requirements, (2) weld metal strength, (3) accessibility, and (4) economics. These factors can directly affect the quality and strength of the weld joint, the ability of the welder to make the weld joint, and the economics of manufacture.

A weld joint designed for a given load requirements must be able to transfer any stresses between the structure and weldment. Service requirements for weld joint design are environment related. Design for corrosion resistance is an example of a service requirement. Weld joint designs have different characteristics. A butt joint is better than a lap joint for improved stress flow, corrosion and fatigue resistance, but with a sacrifice in welding ease.

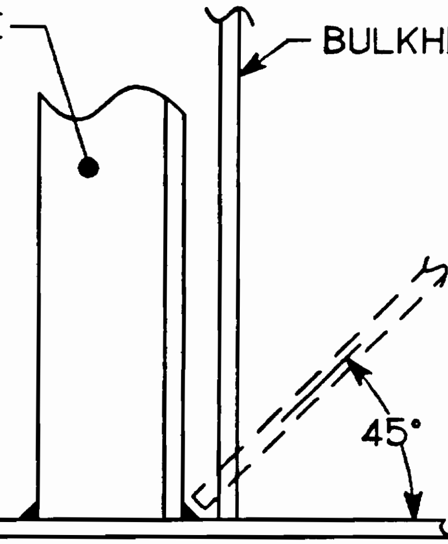
The strength of a weld joint is directly related to the strength of the filler metal and amount deposited. Butt and corner weld joints require a filler material of at least equal strength to the weaker member of the joint to transfer 100% of the load across the weld joint. However, for a tee joint, this is not a requirement since the fillet weld can be increased in size to compensate for its lower strength. If the fillet weld becomes larger than 5/8 of an inch, a partial or full penetration weld joint may be more economical.

Accessibility is another factor to be considered by the design engineer. Figure 6 shows examples of good and bad designs in terms of accessibility. The size of weld machines and their components, such as a welding gun, must have an adequate access to the weld joint. This may require moving a weld joint or altering the structure's assembly sequence.

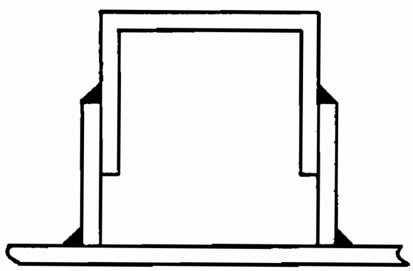
Finally, the design of a weld joint must be economical. The cross-sectional area should be designed to take advantage of the individual welding process that will be utilized. The amount of filler metal needed is a function of the cross-sectional area of the weld joint. The higher



POOR DESIGN, WELDS INSIDE CHANNEL ARE INACCESSIBLE



ANGLE TOO CLOSE TO BULKHEAD TO ALLOW FOR PROPER ELECTRODE POSITIONING



GOOD DESIGN ALL WELDS ARE ACCESSIBLE

Figure 6. Design for Joint Accessibility.

the amount of weld, the higher the chance for weld distortion. For this reason, weld sizes should be kept as small as possible. In the following sections, design considerations for different weld joint designs are discussed.

3.4.1 Fillet Weld Design

Figure 7 illustrates the basic parameters of a fillet weld. In a typical ship hull construction, about 75% of the welds are fillet type [16]. That is, a ship hull is essentially composed of a number of panel structures. Each panel structure is composed of a plate and transverse and longitudinal stiffeners. Stiffeners are fillet welded to the panel since the webs of stiffeners are usually not thick enough to economically use partial or full penetration tee weld joints. The panel is then welded to a continuous member which forms a tee joint.

The shear strength of the fillet depends on the throat dimension, and often determined by multiplying the leg dimension by 0.707. The strength of the fillet weld can be increased by increasing the size of the fillet. However, doubling the fillet size will increase its cross-sectional

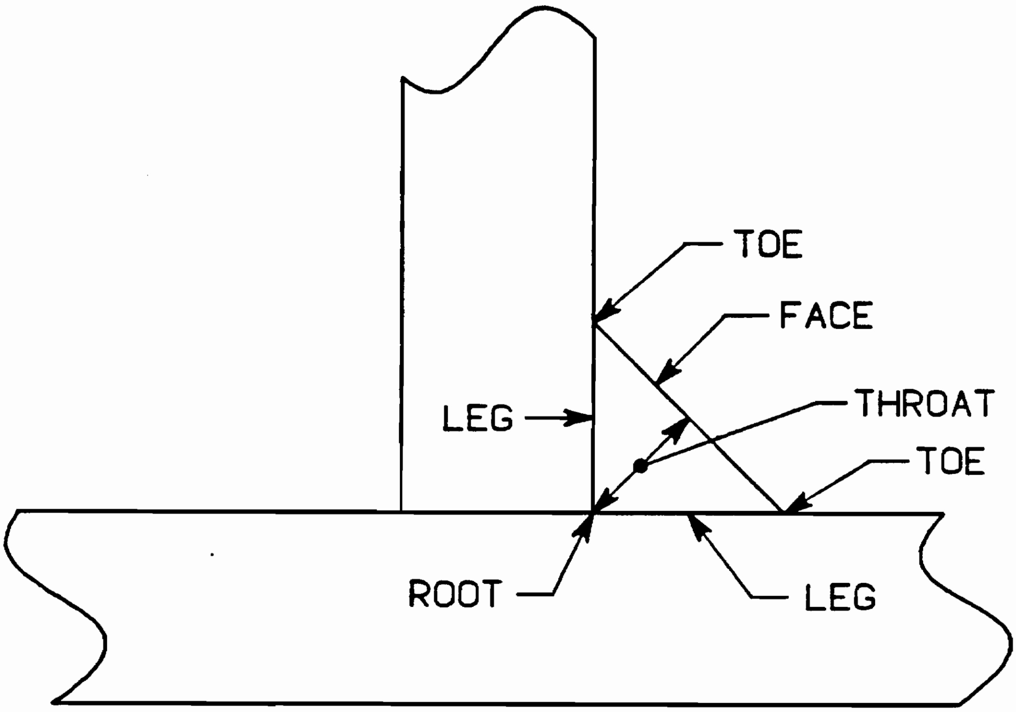


Figure 7. Basic Parameters of a Fillet Weld.

area and weight by four times as shown in Figure 8. Therefore, it is important not to over design the weld because of its impact on cost, time, and weight [10].

The major advantages of the fillet weld design are as follows [5,6,17]:

1. Less base metal edge preparation.
2. Ability to use large-diameter electrodes at high deposition rates.

The major disadvantages of the fillet weld design are as follows [5,6,17,18 p.133]:

1. Less favorable shape from the standpoint of irregularities which can produce stress concentrations.
2. Increase in weld volume as the square of the leg size.
3. Low fatigue strength.
4. Potential for a crevice where corrosion can start from a single fillet.

3.4.2 GROOVE WELD DESIGN

A weld made in the groove of a joint is considered a groove weld. Figure 9 illustrates the basic parameters of a groove weld. Groove weld designs can be either single or

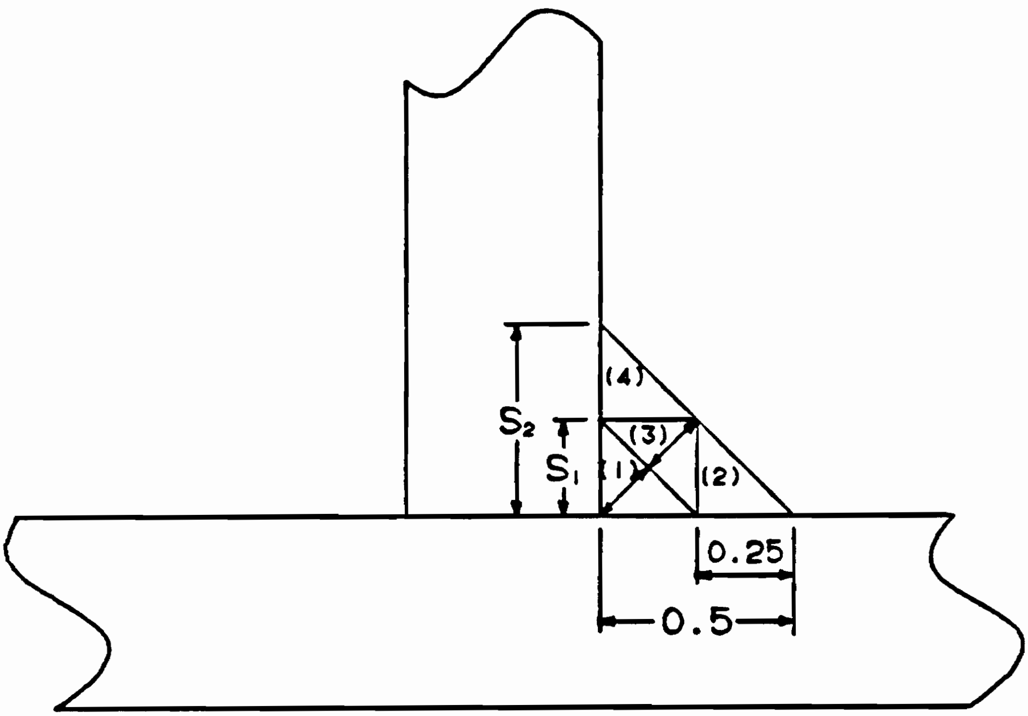


Figure 8. Fillet Weld Strength Versus Cross-Sectional Area.

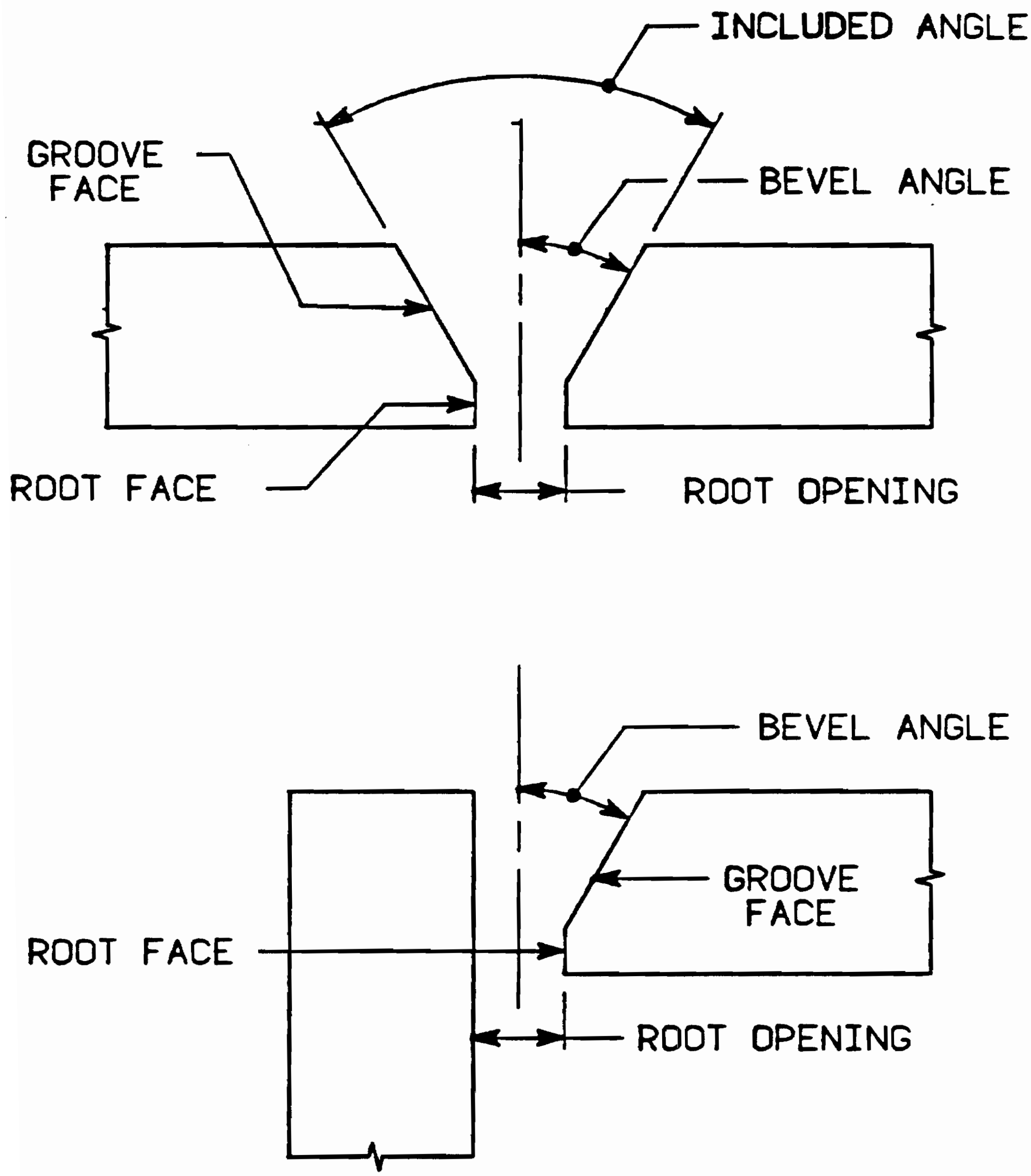


Figure 9. Basic Parameters of Groove Welds.

double groove welds. Figure 10 illustrates the most common groove welds in ship construction. The square groove weld is the simplest since plate edge preparation is not required. However, the square groove joint design is limited to thin materials, usually 1/4 inch and less, because it does not allow for good weld penetration. The bevel and V joint designs require edge preparation, usually by flame cutting, and are often used for material thickness above a 1/4 of an inch. The U and J joint designs are the least common groove welds used in ship hull construction, since edge preparation requires machining. Therefore, the bevel and V joint designs are the preferred ones in ship hull construction.

The amount of filler metal needed is a function of the cross-sectional area of the joint. On thicker materials, a double bevel instead of a V joint design can save considerable weld material. For example, in welding two one inch plates, the single V requires 0.577 square inches of weld metal and the double V joint requires 0.290 square inches of weld metal as shown by Figure 11. Therefore, by using a double V instead of a single V on an one inch plate, a 100% savings in weld metal deposited can be achieved.

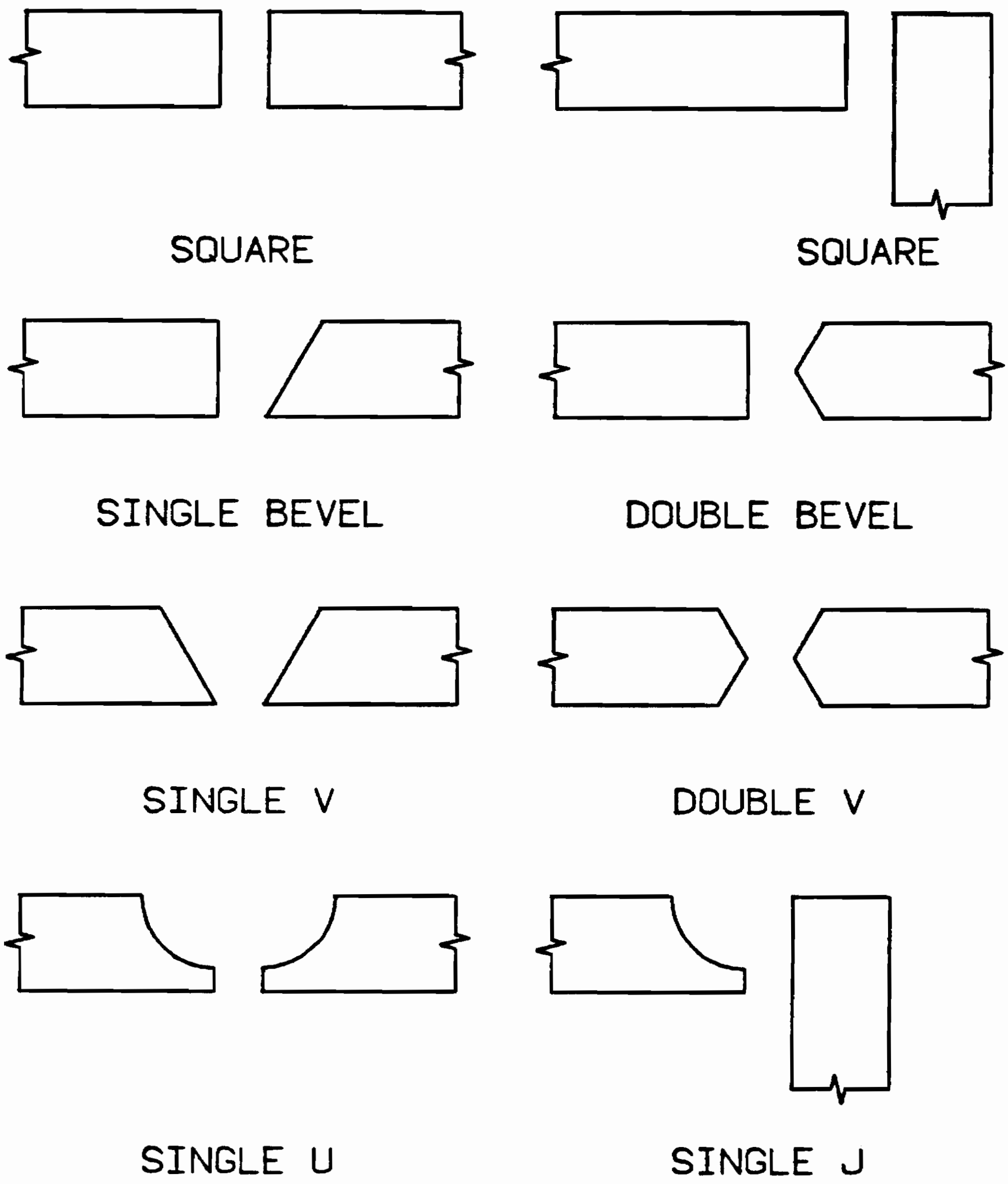
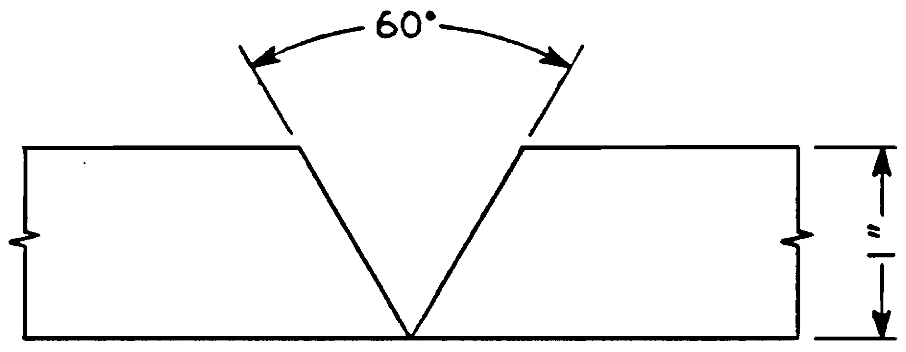
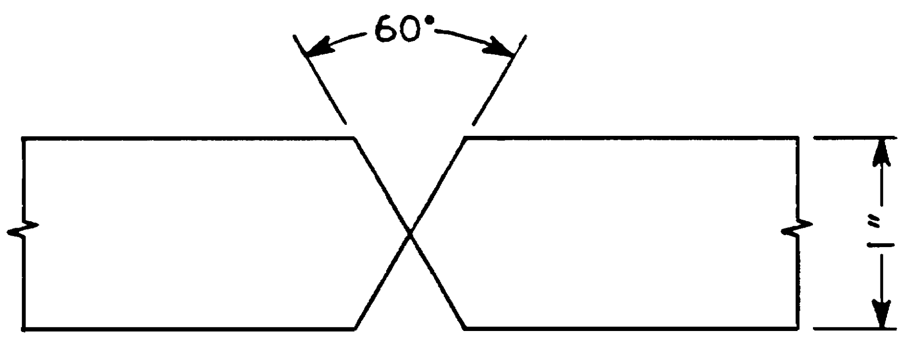


Figure 10. Common Groove Weld Types.



WELD CROSS SECTIONAL AREA = 0.577 IN^2



WELD CROSS SECTIONAL AREA = 0.2885 IN^2

Figure 11. Weld Area Comparison Between Single V and Double V.

These savings in filler metal will cover any added costs for edge preparation.

Accessibility is another factor to be considered in the design of a groove weld. A sufficient room to place the welding electrode into the grooved joint must be addressed. If the included angle is not large enough or the root opening is too tight, an acceptable weld penetration may not be achieved. The specification Mil-Std-22 [2] provides optimum included angles and root openings for the design engineer to utilize. However, the recommended included angles and root openings are based on the shielded metal-arc welding process capabilities.

The major advantages of the groove weld design are as follows [5,6,17,18 p.138]:

A. Butt Type

1. Favorable shape to reduce stress concentrations.
2. Good fatigue strength.
3. Superior corrosion design.

B. Tee Type

1. Less weld volume on thicker members of equal strength fillet.
2. Superior corrosion design.

The major disadvantages of the groove weld design are as follows [5,6,17]:

1. There is a requirement for plate preparation.
2. For small root openings, small-diameter electrodes are used and thus a slower welding process.
3. For large root openings, extra weld metal will be required and, thus, cost and chance for distortion increase.

3.4.3 BEAD WELD DESIGN

Bead welds are commonly used to achieve some desired material properties, such as corrosion or wear resistance, or dimensions. This is done by a stringer or weave type weld bead. Bead welds can also be used to reduce an over specified root opening size to an acceptable dimension. For steel plates with pits on the surface, bead welds can be used to fill in these notches.

The major advantages of the bead weld design are as follows [1, p.581]:

1. Economical method to correct small dimensional errors.
2. Economical method to give a base metal a local new outer surface.

The major disadvantage of the bead weld design is that it is limited to small area applications [1, p.581].

3.4.4 PLUG WELD DESIGN

Plug welds are used to weld one member to another by overlapping the two members and filling one or more holes in one member. A common use for plug welds in shipbuilding is when a design engineer needs to lap a steel plate over an existing structure to achieve a certain thickness. In order to reduce lamination between two plates, plug welds are used. Plug welds should only be used when other types can not be utilized [19].

The major advantage of the plug weld design is manifested in applications where one side of the weld joint is inaccessible [1, p.580].

The major disadvantage of the plug weld design is that other weld joint designs are usually superior in terms of stress flow [1, p.580].

Chapter 4

ARC WELDING PROCESSES

Connections between ship structures are usually made by a fusion type welding process, such as arc welding. Fusion welding is the process of joining two metal parts along their two mating surfaces by heating the base metal to a fusion temperature and adding welding filler metal.

The most common arc welding processes used to join hull structures are shielded metal-arc welding (SMAW), gas metal-arc welding (GMAW), submerged arc welding (SAW), and flux-cored arc welding (FCAW). In the following sections, the welding capabilities of these processes are described.

4.1 SHIELDED METAL ARC WELDING

Shielded metal-arc welding (SMAW) is a process in which the heat of the arc melts a small portion of the base metal, the electrode's metal core (filler), and the flux coating the electrode. This mixing of molten base metal and filler metal from the electrode provides the coalescence required to effect joining. Shielding from the atmosphere is achieved by the decomposition of the flux coating the electrode, which produces a shielding gas. This process is also known as "stick" electrode welding [20, p.5.1-1].

Figure 12 illustrates the SMAW process. The coating on the electrode usually contains deoxidizers, and sometimes alloying elements that contribute to the mechanical properties of the weld metal. In addition to providing a slag blanket that protects the weld puddle, the coating oxidizes and decomposes to produce a shielding gas that isolates the oxygen-rich atmosphere from the region of the arc stream. The coating also controls arc characteristics, primarily by producing an ionizing gas that ensures arc stabilization. However, not all weld metal is transferred. These small particles that escape are known as spatter [21].

4.1.1 SMAW CAPABILITIES

The shielded metal arc welding process is a manual welding process and can be used in all positions depending on the type and size of the electrode, the welding current, and the skill of the welder. Most steels and some nonferrous metals can be welded by this process. There is no maximum or minimum thickness limitations but for thicker parts a multiple pass technique is required. Normally the largest

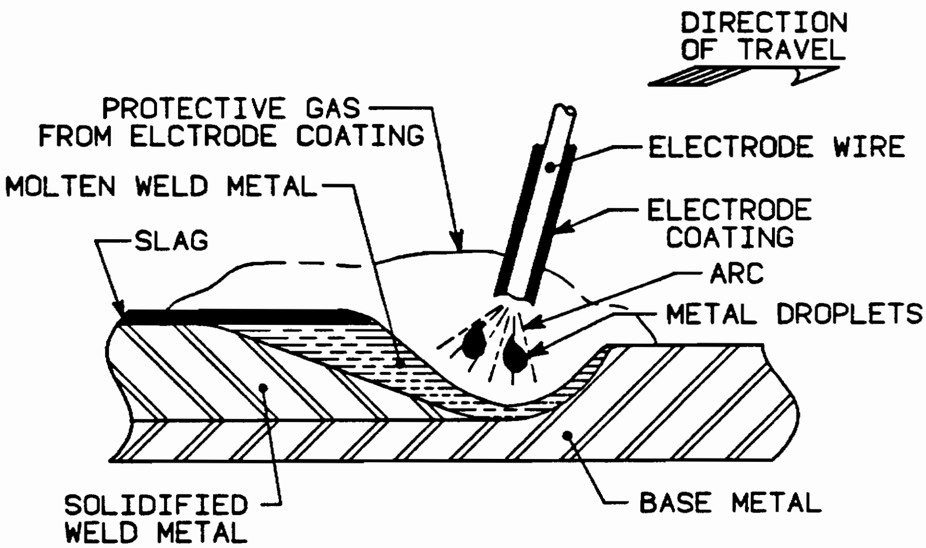


Figure 12. Shielded Metal-Arc Welding Process Diagram [1, p.128].

fillet that can be made in one pass is 5/16 of a inch [22, p.108].

The SMAW process can be utilized for all the weld joint designs given in the Mil-Std-22 specification [2]. Butt and corner joints with material thicknesses over 1/4 inch require some type of groove edge preparation. The fillet is the most common weld and the maximum size for one pass is 5/16 inch. For fillets over 5/16 inch, multi-pass welding technique is required.

4.1.2 ADVANTAGES OF SMAW

The major advantages of the shielded metal arc process are as follows [1 p.128,20 p.5.1-1,21,22 p.108]:

1. It provides maximum flexibility since it can be used in all welding positions.
2. It can weld most steels and some of the nonferrous metals.
3. Equipment is inexpensive, simple to use, and easy to set up.
4. The electrode is wind resistant.

4.1.3 DISADVANTAGES OF SMAW

The limitations and disadvantages of the shielded metal arc process are as follows [1 p.128,20 p.5.1-1,21,22 p.108]:

1. It is a manual process and is difficult to automate.
2. A skilled operator is required and he/she must wear protective clothing and a helmet.
3. The process is slow and has a low operator factor, less than 25%, because of the periodic replacement of electrodes once consumed to within 2 inches of their original length.
4. It has a low filler metal utilization, approximately 65%, because of the amount of electrode and coating lost in the stubs.
5. Slag cleaning is required.

4.2 GAS METAL-ARC WELDING

Gas metal arc welding (GMAW) is a gas-shielded arc welding process that utilizes a bare consumable electrode and gas from an external source for shielding. The electrode is fed continuously to the weld area and becomes the filler metal as it is consumed. A stream of gas, or mixture of gases, is fed through the electrode holder to shield the welding area from contamination [20, p.5.4-1].

GMAW processes can be further classified, based on the type of shielding gas and/or the type of metal transfer being used, into three categories (1) Spray GMAW in which a gas mixture of 95% argon and 5% oxygen is used. This gas mixture allows for high deposition rate welds with extremely smooth surfaces, and thus minimum clean-up is required. (2) Pulsed Arc GMAW in which the current is pulsed at regular intervals to provide discrete transfers of metal across the arc. (3) Short Arc GMAW uses "short circuiting transfer" in which a globule of molten metal collects on the end of the electrode and is blasted into the molten crater due to the short circuit principles of the process [23].

The basic GMAW process is illustrated in Figure 13. The main requirements for this process are (1) a power supply that provides sufficient current to melt the electrode, (2) an automatic wire feeder, (3) a smooth flow of shielding gas, and (4) an electrode holder. The two main parameters that affect the transfer of metal are the shielding gas and the diameter of the wire. The setting of these parameters depends on the metal being welded [1, p.105].

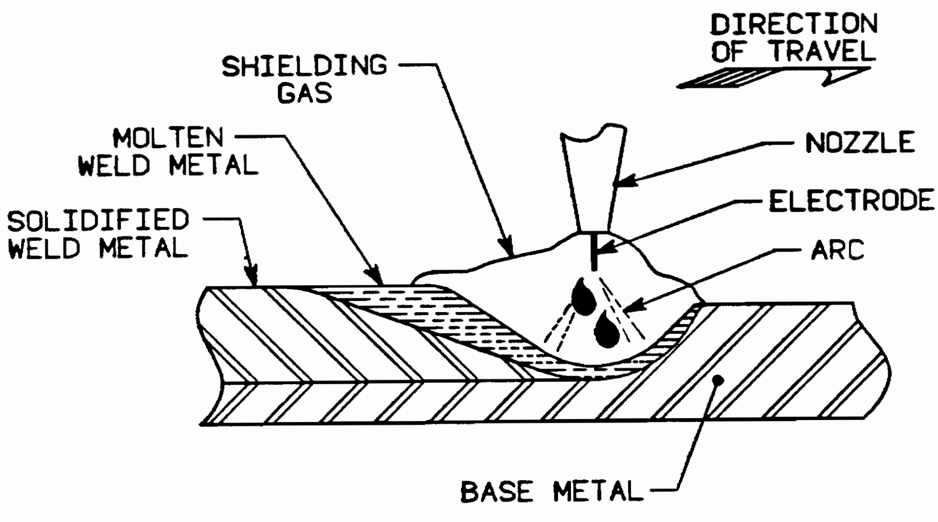


Figure 13. Gas Metal-Arc Welding Process Diagram [1, p.145].

4.2.1 GMAW CAPABILITIES

The gas metal arc welding process can be semi-automatic or automatic. In either case, the bare electrode wire is fed automatically to the electrode holder at a controlled rate, which can be adjusted by an operator or automatically [24, p.2].

In the semi-automatic mode, the equipment controls only the electrode wire feed rate. Manipulation of the welding gun and electrode wire, and starting and stopping of the wire feed, shielding gas flow and current are manually controlled. In some situations, the setup can be fully automatic, where the operator only starts the operation and performs the necessary controlling functions [24, p.2].

The automatic method requires little or no adjustments by the operator. Normally all the operator has to do is to start the equipment. This process can be utilized for most metals and alloys. However, the metals and alloys most easily welded include carbon and low-alloy steels, stainless steels, aluminum alloys, copper alloys, and magnesium alloys [20, p.5.4-2].

The gas metal arc welding process can be used in all positions. It is, however, most efficient in the flat and horizontal positions, but it is at least equal to the shielded metal-arc welding in other positions [20, p.5.4-2].

The GMAW process can be employed for all the weld joint designs given in the Mil-Std-22 specification [2]. However, when using this process, consideration must be given to the location of a particular weld joint. The size and complexity of the equipment may prevent the proper manipulation of the electrode holder in respect to the weld joint. Specifically, groove weld details should be modified to achieve maximum efficiency. The wire electrode of this process is smaller in diameter than the electrode of the shielded metal arc welding process. Therefore, the groove angle of the joint can be reduced since the smaller diameter electrode can be directed to the root of the weld joint using a smaller included angle. This is illustrated in Figure 14 [1, p.147].

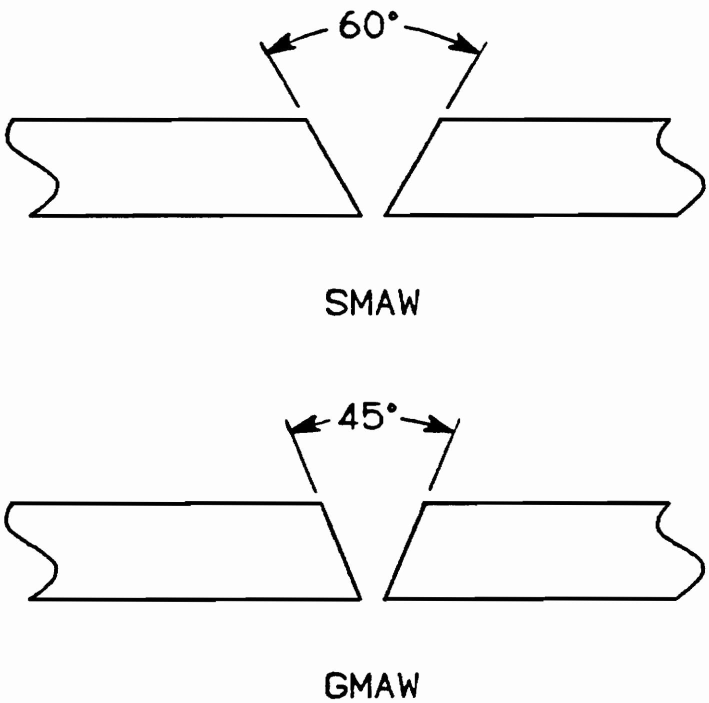


Figure 14. Example of Included Angles for GMAW Versus SMAW [1, p.147].

4.2.2 ADVANTAGES OF GMAW

The principal advantages of GMAW are as follows [1 p.145,20 p.5.4-1,22 p.116,23]:

1. Higher deposition rates as compared to the shielded metal arc welding process, because the filler metal is continuously fed.
2. High operator factor due the ability to mechanize the set-up.
3. High utilization of filler metal because of the ability to use smaller diameter electrodes which make the current density higher and weld-metal deposition rate greater.
4. Absence of slag which must be removed after each pass when using flux or flux coated electrodes.
5. Low operator skill as compared to the manual shielded metal arc welding process.
6. Can be utilized for any welding positions or metal thickness.
7. Can be used on many different metals.

4.2.3 DISADVANTAGES OF GMAW

The disadvantages of the GMAW process are as follows [1 p.145,20 p.5.4-1,22 p.116,23]:

1. Equipment is more complex to operate, expensive and not portable.
2. It is less adaptable for welding in difficult-to-reach areas.
3. This process is susceptible to weld-metal cracking because there is no slag cover to reduce the rate of cooling.
4. There is no protection against strong drafts which can blow the stream of shielding gas away from the weld.

4.3 SUBMERGED ARC WELDING

Submerged arc welding (SAW) is an arc welding process whereby the arc is shielded from the atmosphere by a blanket of fusible granulated material known as flux. Joining is accomplished by the heat created by the electric arc between a bare metal electrode (in which the tip is submerged in the flux) and the weld pool as shown in Figure 15. The bare metal electrode is not in direct contact with the weld pool, rather the current is transferred through a gap containing gases from the decomposed flux. Since the arc is completely

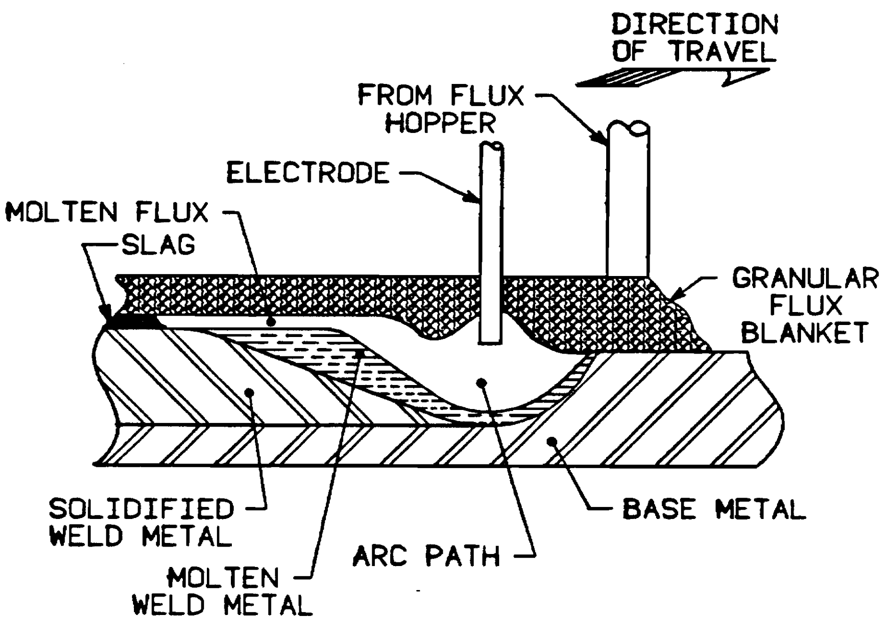


Figure 15. Submerged Arc Welding Process Diagram [1, p.164].

covered by an envelope of molten flux, which is covered by unfused flux still in a granulated form, there is no visible evidence of flash, spatter, and sparks which exist in other open-arc processes such as SMAW or GMAW process [20, p.5.2-1].

4.3.1 SAW CAPABILITIES

The SAW process can be either automatic or semi-automatic dependent on the following factors: (1) production volume, (2) weld length, (3) weld accessibility, (4) weld quality and (5) weld appearance. In either case, the process is limited to flat or horizontal welding positions, because of the high weld deposit rate which creates a large molten pool of weld and slag that could run out of the weld joint [1, p.164].

The SAW process can be utilized for all the weld joint designs given in the Mil-Std-22 specification [2]. SAW is a deep penetration process, and thus substantial savings in welding wire consumption can be achieved. For example, for fillet welds the SAW deep penetration capability means that a smaller weld size of the same strength as a larger one can be achieved. That is, in ship design, the weld shear strength is important when determining fillet weld size requirements. Shear strength is dependent on the throat dimension of the fillet, traditionally determined by multiplying the minimum leg dimension by 0.707. This approach assumes that the fillet penetrates to the corner of the joint. Figure 16 shows that the SAW process can produce throat depths 20 to 30 percent greater than the SMAW process. Therefore, with this increased penetration capability, a smaller fillet weld can have the same strength as a larger one built-up on the outside, and in turn results in cost savings [25, p.5].

For butt welds of square design, welding can be done from one side and up to 3/8 inch thick. To assure full penetration, however, backing bars should be used for one side weld. When both sides are accessible, the square groove design can be used for up to 1/2 inch thicknesses [26, p.7].

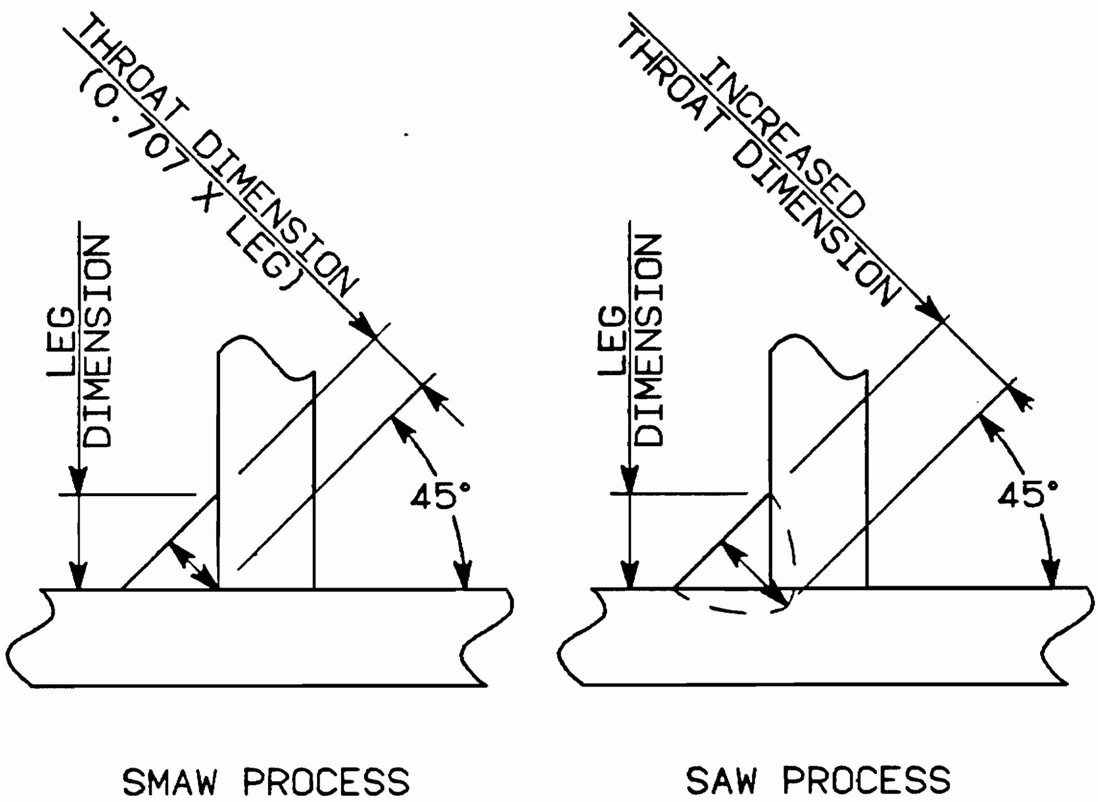


Figure 16. Diagrams Showing Increased Penetration of SAW over SMAW for Fillet Welds.

4.3.3 ADVANTAGES OF SAW

The SAW process has the following advantages when compared with other arc welding processes [1 p.164,8,20 p.5.2-1,22 p.119]:

1. High quality weld is achievable.
2. The deep penetration capability results in small amount of weld metal required and lower joint preparation requirements.
3. No special clothing or a helmet are required to operate the equipment.
4. Increased operator comfort due to reduced exposure to smoke and heat.
5. This process can be used at extremely high deposition rate and speed.
6. The flux acts as a cleanser to remove undesirable contaminants from the weld puddle to produce smooth uniform finished weld with no spatter.
7. It has high utilization of inexpensive electrode wires and fluxes for welding low carbon steels.
8. When welding in exposed areas with relatively high winds, the flux provides superior shielding protection than does gas shielding techniques.
9. High skilled operators are not required.

4.3.4 DISADVANTAGES OF SAW

The disadvantages of the SAW process are as follows [1 p.164,8,20 p.5.2-1,22 p.119]:

1. The welding position is limited to flat or horizontal surfaces.
2. It can only be used on steels.
3. Flux, flux-handling equipment, and work fixtures are required.
4. Flux is subjected to contamination from moisture, rust, mill scale and other foreign substances which can cause weld porosity.
5. Base metal must be free of rust, oil and other contaminants.
6. It is not suitable for thin material thicknesses of less than 3/16 inch thick because of burn through tendencies.
7. Slag must be removed.
8. If the weld joints are not butted tight together, then a backing bar must be used as a support to avoid burn through.
9. It is not usually suitable for short runs.
10. Weld accessibility is limited due to equipment size.

4.4 FLUX-CORED ARC WELDING

Flux-cored arc welding (FCAW) is an arc welding process that joins metals by heating them with an electric arc between a tubular consumable electrode wire and the work metal (see Figure 17). Self-shielding is provided by the flux contained within the tubular consumable electrode. Gas is released during combustion and decomposition of the flux shields the weld joint. Additional shielding can be supplied externally in the form of gas, usually carbon dioxide. Thus there are two variations; one method is self shielding from the flux in the core of the electrode, and the other one adds an auxiliary shielding gas [1, p.155].

The FCAW process is closely related to other arc welding processes. The self-shielding FCAW and the shielded metal-arc welding (SMAW) processes are similar in that both depend on the combustion and decomposition of a solid flux to provide the gaseous shield. The SMAW process, however, has its flux on the outside of the electrode which limits the form of the electrode to the stick type. For the FCAW process tubular electrodes on spools or coils are available and supplied to the electric arc as a continuous wire. The auxiliary gas shield FCAW is similar to the gas metal-arc

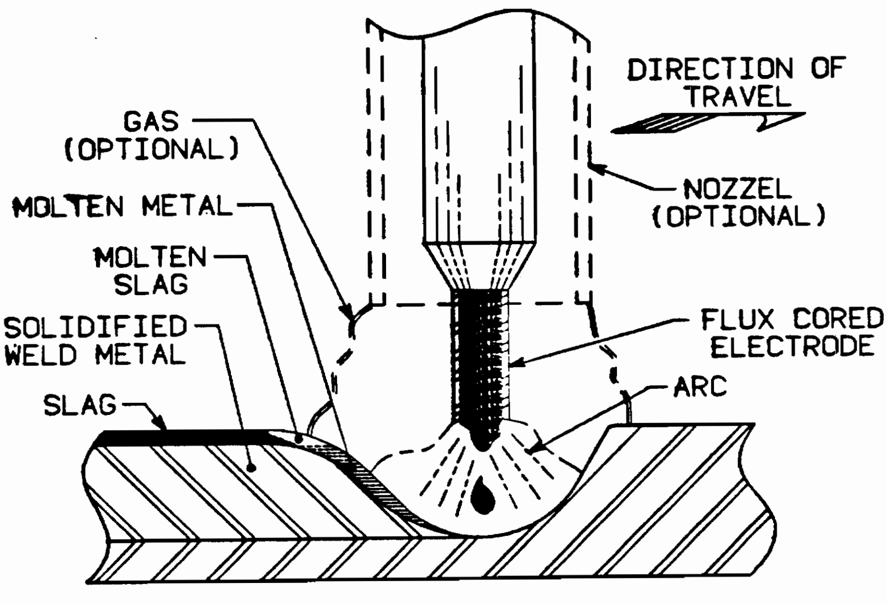


Figure 17. Flux-cored Arc Welding Process Diagram [1, p.155].

welding (GMAW) process. Both methods employ a continuous wire and depend on externally supplied gas to shield the electric arc and molten metal from contamination by the atmosphere [22, p.111].

4.4.1 FCAW CAPABILITIES

The FCAW process can be either automatic or semi-automatic, and can be utilized for all welding positions dependent on the electrode size. The self-shielding FCAW method has the following features: (1) does not require auxiliary gas, gas supply, control and gas nozzle, (2) can be used in a draft, and (3) provides moderate penetration. The auxiliary gas FCAW method provides the following features: (1) deep penetration, (2) sound deposits, and (3) high quality smooth welds. However, both methods are restricted to the welding of carbon and low-alloy steels [22, p.111].

The FCAW process can be utilized for all the weld joint designs given in the Mil-Std-22 specification [2]. For fillet welds, the deep penetration capability of the auxiliary gas shielded FCAW process means that a smaller fillet weld of same strength as a larger fillet one deposited by other processes can be achieved as shown in Figure 18. However, the self-shielding FCAW does not have the same deep penetration capability as the auxiliary gas shielded method and therefore fillet sizes cannot be reduced [1, p.156].

For groove welds and the auxiliary gas shielded FCAW method, the cross-sectional areas can be reduced from that given in the standard [2] because smaller size electrode wire can get deeper into the joint. This increased penetration allows for narrower grooves and can accommodate thicker unbeveled plates of up to 5/8 inch thickness. For thinner plates the self-shielding FCAW method allows for better control due to its moderate penetration and less chance of burn-through [1, p.156].

4.4.2 ADVANTAGES OF FCAW

The FCAW process provides a lower deposition cost per pound and requires less welder training than the shielded metal arc welding process. Also it is more forgiving than the gas metal arc welding, and is more flexible and adaptable than the submerged arc welding process. The advantages are summarized as [1 p.155,8,22 p.111]:

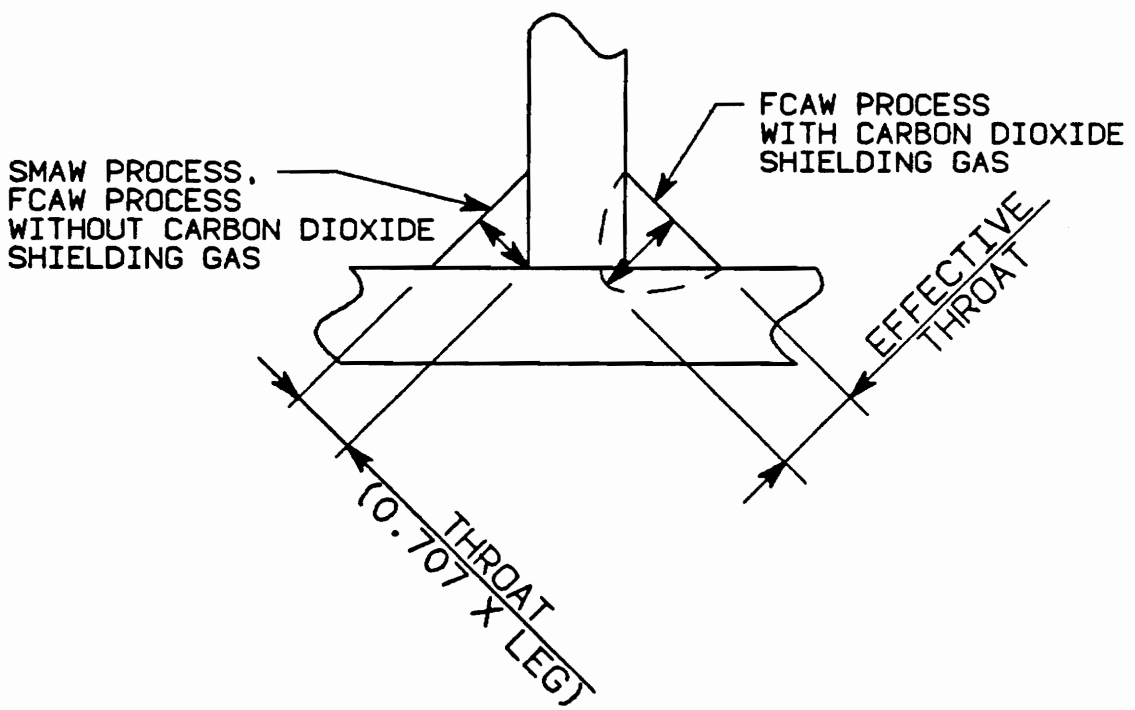


Figure 18. Diagram Showing Increased Penetration of FCAW with CO2 for Fillet Welds.

1. It has high deposition rates.
2. Excellent quality welds can be achieved in all positions.
3. Deeper weld penetration permits efficient weld joint designs.
4. There is no weld spatter because the electric arc operates under a flux cover.
5. Flux acts as a scavenger and deoxidizer to remove undesirable contaminants from the weld puddle.
6. This method is easily automated to eliminate the need for skilled operators.
7. Smooth uniform finished welds are readily achieved.
8. This method can weld a variety of thicknesses.
9. It provides reduced weld distortion as compared to the shielded metal arc welding process.
10. It has fast freezing slag and thus can be easily removed.
11. Minimum joint preparation requirements.
12. Deposition efficiency in the electrode is relatively high.

4.4.3 DISADVANTAGES OF FCAW

The disadvantages of the FCAW process are as follows [1, p.155,8,22 p.111]:

1. It is limited to primarily low carbon and alloy steels.

2. Slag must be removed from the weld bead after each weld pass.
3. Flux-cored electrode wire is more expensive per unit weight basis than solid bare electrode wires used in the SAW and GMAW processes.
4. The auxiliary gas FCAW type requires low wind drafts for efficient operation.
5. Equipment is expensive but easily justifiable with increased productivity.

Chapter 5

THE DEVELOPED SYSTEM

Cost optimization of the many activities involved in the production of a product has been and will be a main goal and a driving force for many manufacturers. Normally, cost reduction is considered at departmental levels, such as design, manufacturing and marketing, with the assumption that the sum of all these cost reductions will be an optimal one. For example, design and manufacturing activities are sequentially performed and independently optimized. However, in today's manufacturing environment, better methods for achieving a true optimal cost are needed. Such methods must be geared towards a total system approach instead of an independent departmental approach [27, p.14].

Typically, a product's design cost is around 5% of the total cost, but the design usually dictates more than 70% of the manufacturing cost [3]. This is, in part, due to the sequential decision making of design and manufacturing. Once a product design is completed, the designer releases the documents to the manufacturing group who have at best 30% of the product cost to optimize. Therefore, the integration of manufacturing considerations and other related aspects of the product life cycle, such as maintenance and repair, early in the product design phase is the only means for achieving an optimal cost reduction.

The methods developed to facilitate such an integration can be classified into two groups: managerial and automatic methods. Managerial methods deal with the problems encountered in creating and managing teams made up of professionals who are expert in these many activities of the product life cycle, such as concurrent or simultaneous engineering approaches [28]. Automatic methods deal with the design and implementation of frameworks or methodologies by which such an integration is automatically facilitated [29]. For example, the designer would have all the information pertaining to the impact of different product design decisions or alternatives on all the cost components of a product available at his/her disposal. Such information can be in the form of a look up guide or software.

Examination of the literature indicates that a framework or a methodology for welded structures design has not yet been developed. Nonetheless, some aspects of such a framework have been addressed in the literature, such as cost comparisons of different welding processes for a given application [7] and guidelines for better weld joint design [6].

Therefore, the objective of this research work is to develop a framework that facilitates the automatic integration of manufacturing considerations early in the design of welded structures. The developed framework or system allows the designer to select an optimal welding process for a given application. Manufacturing factors considered by the system, described in detail in the first section of this chapter, include deposition rate, operator factor, deposition efficiency, welding position, accessibility, weldability, and joint design. Other manufacturing factors that have not been considered by the developed system include selection of a filler metal or a shielding gas, and welding parameters related to process optimization. The inclusion of the selection of a weld metal or a shielding gas in the system for cost optimization may have a deterrent impact on the weld quality [30]. Factors limited to the optimization of a welding process are typically manufacturing oriented and have little impact on the decision making during design. Other factors that were not considered in the system design include nondestructive testing and production scheduling.

The design engineer task is, therefore, to investigate the appropriate trade-offs between the manufacturing factors considered by the system at an early stage in the design process. The impact of different design alternatives are supported by expected costs. The system boundary is limited to the welding processes of SMAW, GMAW, SAW, and FCAW (described in detail in Chapter 4), and the major steels of mild, high tensile, HY80, and HY100 (commonly used in the construction of hull non-nuclear structure for surface combatant ships in the U.S. Navy).

5.1 SYSTEM FACTORS

5.1.1 DEPOSITION RATE

The deposition rate is the amount of weld metal deposited into a weld joint per unit of time. The deposition rate is affected by welding current, type and size of filler metal, welding process and position, electrode stickout (electrode extension), and polarity. The deposition rate can be expressed in volume or weight and does take into consideration spatter and slag losses [1, p.118]. However, it is commonly defined as:

$$\text{Deposition Rate (DR)} = \frac{\text{LBS}}{\text{Unit Time}}$$

Table 1 provides the obtainable deposition rates (pounds/hour) of the SMAW, GMAW, FCAW, and SAW processes for different welding positions. These rates are for welding a 3/4 inch fillet weld to join two one-inch thick plates of carbon steel, and for welding a double V-butt that is two inches thick with a 40 degree included joint angle. As shown in Table 1, fillet joints allow for a higher deposition rate than the butt type.

5.1.2 OPERATOR FACTOR

The operator factor is the ratio of actual welding hours to total working hours, such as 8 hours a day. This factor is low for the manual SMAW process due to the periodic change of electrodes, and high for the automatic type processes because weld metal wire is continuously fed. The operator factor is commonly defined as [20, p.12.1-5]:

$$\text{Operator Factor (OF)} = \frac{\text{Arc Time}}{\text{Total Time}}$$

Table 1. Deposition Rate Versus Position [7,33].

PROCESS	WELD TYPE	MANUAL DOWNHAND LB/HR	MANUAL VERTICAL LB/HR	MANUAL OVERHEAD LB/HR
SMAW	FILLET	6	1.5	0.75
SMAW	BUTT	3.1	1.4	1.4

PROCESS	WELD TYPE	AUTOMATED DOWNHAND LB/HR	SEMI-AUTOMATED DOWNHAND LB/HR	SEMI-AUTOMATED VERTICAL LB/HR	SEMI-AUTOMATED OVERHEAD LB/HR
GMAW (1)	FILLET	20	10	2.5	1.3
GMAW	BUTT	N/A	6.6	6.6	6.6
FCAW (2)	FILLET	20	10	2.5	1.2
SAW	FILLET	55	27	---	---
SAW	BUTT	18	12	---	---

(1) ARGON SHIELDING

(2) CARBON DIOXIDE SHIELDING

The operator factor is affected by the welding process and position, the welder's skill, type of filler metal and shielding gas utilized, welding procedures, and preparation and cleaning requirements. Table 2 lists the average operator factors of SMAW, GMAW, FCAW, and SAW processes in their various modes of operation.

5.1.3 DEPOSITION EFFICIENCY

The deposition efficiency is the amount of filler metal deposited per weight of electrode consumed. It takes into account the loss of electrode material as shielding vapor, slag, and spatter. The SMAW process has the lowest deposition efficiency since flux is converted into a shielding gas and slag on the surface of the weld. Also, this process results in a lot of spatter. On the other hand, the SAW process has the highest deposition efficiency because the flux is separately applied and spatter is essentially nonexistent. The deposition efficiency factor is commonly defined as [20, p.12.1-5]:

$$\text{Deposition Efficiency (DE)} = \frac{\text{WT. of Weld Metal Deposited}}{\text{Weight of Weld Metal Consumed}}$$

Table 2. Average Operator Factors [7].

PROCESS	OPERATOR FACTOR
SMAW (MANUAL)	0.2
GMAW (SEMI-AUTOMATIC)	0.3
GMAW (AUTOMATIC)	0.5
FCAW (SEMI-AUTOMATIC)	0.3
FCAW (AUTOMATIC)	0.5
SAW (SEMI-AUTOMATIC)	0.3
SAW (AUTOMATIC)	0.5

Deposition efficiency depends on the welding process, filler metal, and shielding gas for GMAW and FCAW processes or flux for SAW process. Table 3 provides average deposition efficiencies for SMAW, GMAW, FCAW, and SAW processes.

5.1.4 WELDING POSITION

The rate of welding is affected by the welding position, unless the appropriate electrode is used. Different electrode compositions are available for different welding positions. For the SMAW process, a "fast-freeze" electrode is recommended for overhead and vertical joints. It solidifies rapidly to fight the gravity force. For flat and horizontal joints, a "fast-fill" electrode is used for rapid deposition [20, p.6.2-15]. On the other hand, the SAW is limited to flat and horizontal joints because feeding the externally supplied flux relies on gravity. The operator factor is affected by the welding position. Overhead welding requires higher skill than downhand welding. Table 4 lists the welding positions that the SMAW, GMAW, FCAW, and SAW can accomplish.

Table 3. Deposition Efficiencies [33].

PROCESS	DEPOSITION EFFICIENCY
SMAW	69%
FCAW	85%
GMAW	90%
SAW	100%

Table 4. Welding Positions.

PROCESS	WELDING POSITIONS
SMAW	ALL
FCAW	ALL
GMAW	ALL
SAW	FLAT AND HORIZONTAL ONLY

5.1.5 ACCESSIBILITY

The complexity of the electrode holders of the GMAW, SAW, and FCAW welding processes makes these processes less versatile than the SMAW process for applications in which welding is done on intricate assemblies that have joints in difficult-to-reach locations. A design that limits accessibility or requires a poor electrode position can have a negative effect on deposition rates and also increases the possibility of excessive spatter, poor penetration, poor bead shape, and rework [31].

Accessibility is relative and the indicators that will be used to describe it are maximum, average, and minimum. Maximum accessibility indicates that there are no obstructions to interfere with the welding operation. Maximum accessibility requires at least 24 inches abreast, 12 inches forward and back, and 48 inches vertically of clear space in the way of the weld joint. Average accessibility indicates that there is a minor obstruction with at least 3 inches abreast, and 6 inches forward, back, and vertically of clear space. Minimum accessibility indicates that there is a major obstruction, interfering

Table 5. Required Weld Joint Accessibility.

PROCESS	ACCESSIBILITY
SMAW (MANUAL)	MINIMUM
GMAW (SEMI-AUTOMATIC)	AVERAGE
GMAW (AUTOMATIC)	MAXIMUM
FCAW (SEMI-AUTOMATIC)	AVERAGE
FCAW (AUTOMATIC)	MAXIMUM
SAW (SEMI-AUTOMATIC)	AVERAGE
SAW (AUTOMATIC)	MAXIMUM

with the welding operation, with less than 3 inches abreast, 6 inches forward, back, and vertically of clear space. Table 5 lists the accessibility requirements of the SMAW, GMAW, SAW and FCAW processes for manual, semi-automatic and automatic methods.

5.1.6 WELDABILITY

Weldability can be measured by the number of metals on which a process can be used. The welding processes of SMAW and GMAW can be used to weld most steels and some of the nonferrous metals. The SAW and FCAW processes are, however, mainly limited to steels because the granular flux used is compatible only with steels. Table 6 lists the weldability aspects of mild steel (MS), high tensile steel (HTS), HY80, and HY100 steels.

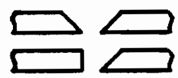
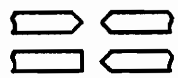
5.1.7 WELD JOINT DESIGN

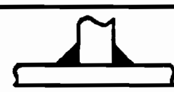
Weld joint designs are usually biased to the SMAW process capabilities, given in Table 7. To take advantage of the newer welding processes, different weld design considerations are required to optimize the weld joint. The SAW and FCAW with carbon dioxide shielding process have

Table 6. Weldability.

PROCESS	STEEL			
	MS	HTS	HY80	HY100
SMAW	YES	YES	YES	YES
GMAW	YES	YES	YES	YES
SAW	YES	YES	YES	YES
FCAW	YES	YES	YES	NO

Table 7. Typical Weld Joint Designs for the SMAW Process.

JOINT	WELD	MAXIMUM THICKNESS	SKETCH
BUTT	SQUARE	≤ 1/4	
	V AND BEVEL	> 1/4 ≤ 3/4	
	DOUBLE V DOUBLE BEVEL	> 3/4	
CORNER	SQUARE	≤ 1/4	
	BEVEL	> 1/4 ≤ 3/4	
	DOUBLE BEVEL	> 3/4	

JOINT	WELD	MAXIMUM REINFORCEMENT	SKETCH
TEE	FILLET	≤ 5/8	
	PARTIAL PENETRATION	≤ 5/8	
	FULL PENETRATION	≤ 3/8	

NOTE: FOR LAP AND EDGE JOINTS CHECK SHIP SPECIFICATION FOR LIMITS.

superior penetration capabilities which can be used to reduce the size of fillet welds. The GMAW, SAW, and FCAW processes have smaller diameter wires and greater penetration characteristics than the SMAW "stick electrode." This can be used to modify bevel angles of weld joints to reduce the amount of weld volume.

5.2 SYSTEM DESIGN

A structural series of steps was utilized to develop the system. This includes (1) system analysis, (2) synthesis, the combination and structuring of components to form a system that meets specific objectives, (3) appraisal of system performance, and (4) feedback from system evaluation at predetermined intervals to improve the design. Data collection is a continuous process and hence is not listed in the following system development steps, shown in Figure 19 [32, p.1-8]. The following steps were used to develop the system:

(1) Define the specific goals of the system.

(2) Identify the objectives and boundaries of the system.

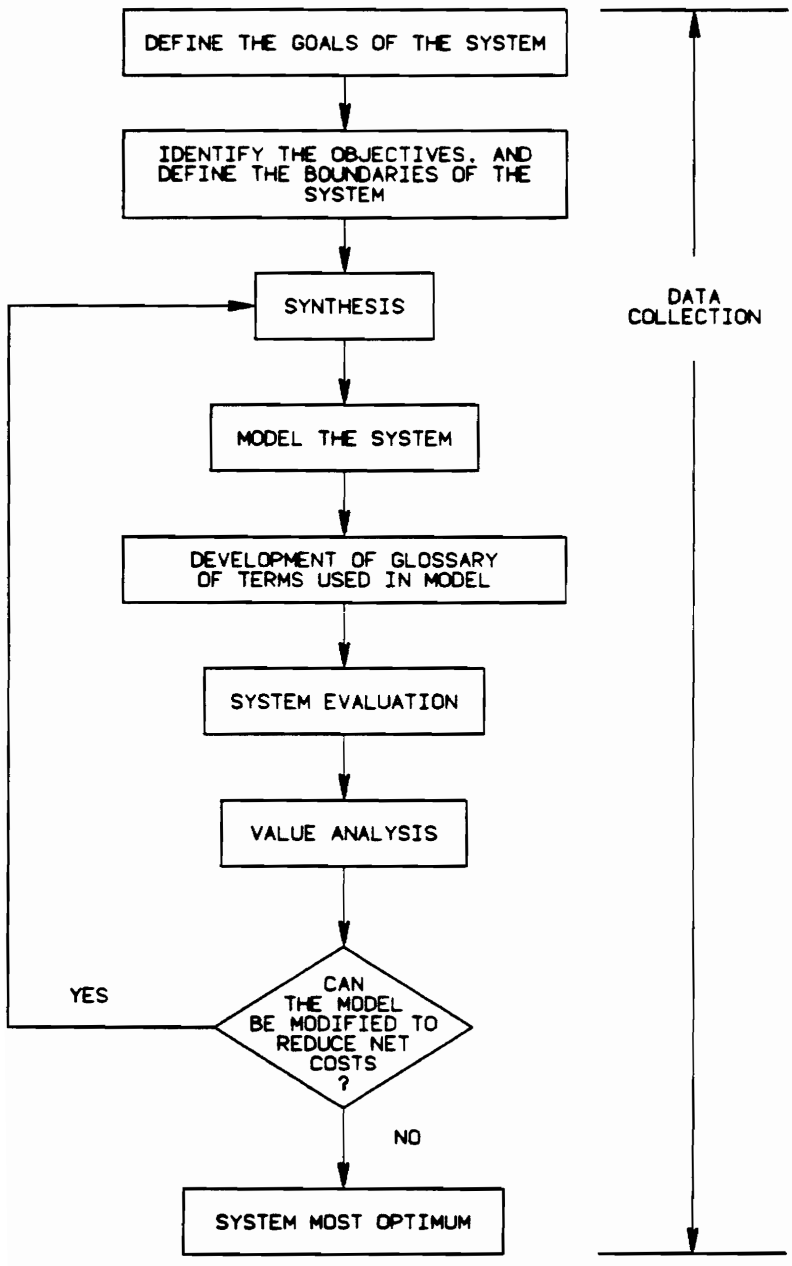


Figure 19. Steps of System Design.

(3) Synthesis, which refers to the selection of components to form a functional entity that meets specific objectives and constraints. This is done by relying on past experiences, knowledge, imagination, and creative skills and advice from consultants, experts, etc. to help in part/whole of system design.

(4) Modeling, which deals with the scope, depth and structure of the system.

(5) Development of a glossary of terms used including expressions.

(6) Verification and evaluation to determine if all objectives and constraints are met.

(7) Value analysis, which is the measurement of expected benefits from the system. The first phase of the value analysis concentrates on the individual components of the system to determine its nature and interaction with other components. Each component is subjected to the following questions [32, p.1-11]: (1) What does it do?, (2) How does it influence other components?, (3) What function does it serve?, (4) Can it be eliminated?, and (5) Can

another component assume its task?

The second phase of value analysis is to determine the cost benefits of each component that was analyzed. In this phase, the system is subjected to questions such as: (1) Will other components be affected by adopting an alternative cheaper component or by combining some components for cost purposes? and, (2) Does the new system have a net cost savings? [32, p.1-11].

(8) Selection of most optimum system design.

5.3 SYSTEM STRUCTURE

The goal of the developed system is to provide the design engineer with a structured decision framework so that a cost-effective welded structure design can be achieved. The system structure is presented in the form of a flow chart in Figure 20. It integrates manufacturing considerations into the design cycle for the objective of selecting an appropriate welding process early in the design cycle. Each component has different sub-levels and are discussed in detail below.

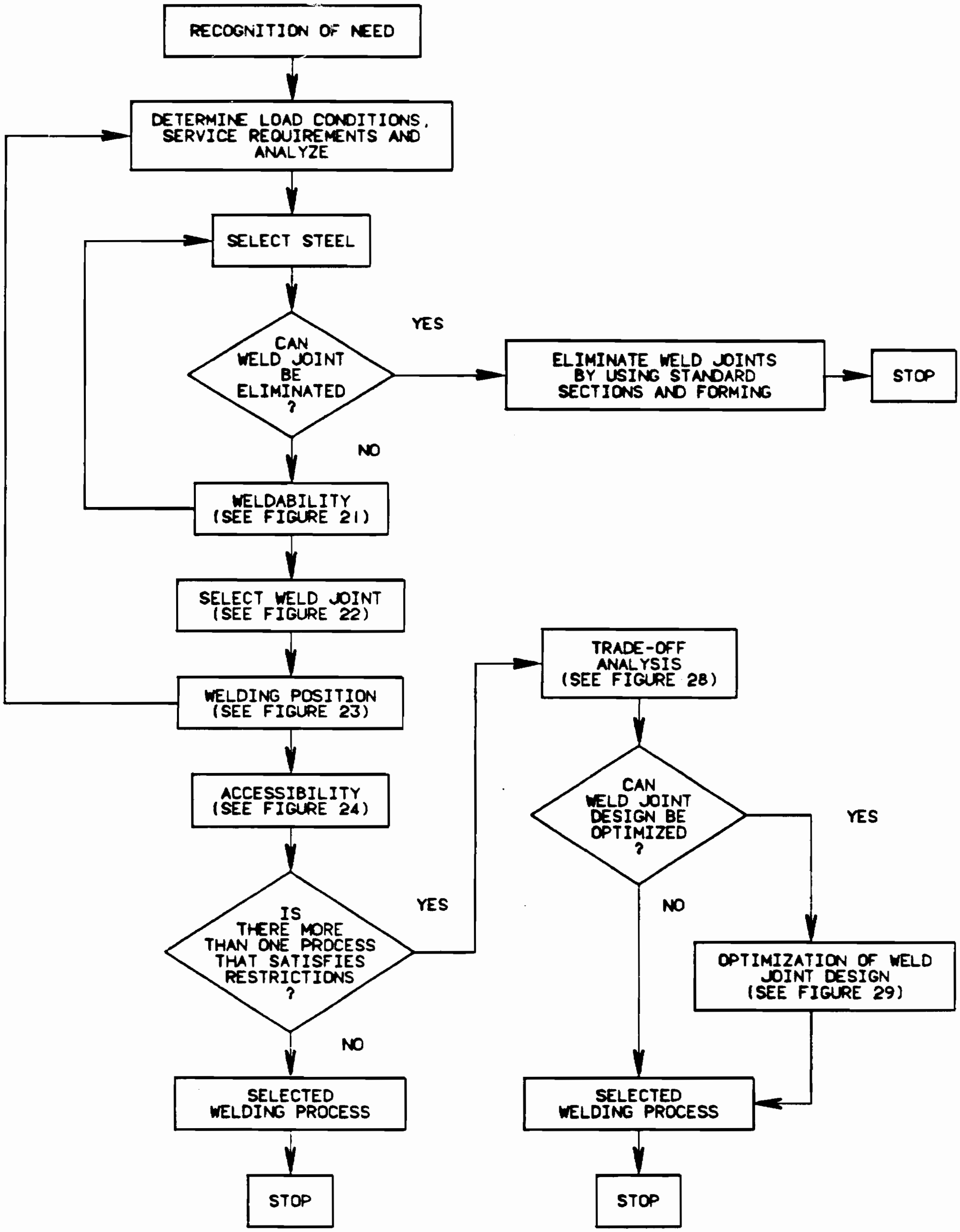


Figure 20. System Structure.

RECOGNITION OF A NEED

This component recognizes that before the system starts there must be a possible welded structure design for a given application.

DETERMINE LOAD CONDITIONS, SERVICE REQUIREMENTS, AND ANALYZE

The load conditions and service requirements for U.S. Navy ship structure are governed by certain specifications [35]. These specifications are sets of rules which insure that a ship's structure will meet designated standards of quality, strength, reliability, maintainabilty, etc. Next, a detailed stress analysis is performed to select an appropriate steel.

SELECT STEEL

The current system includes only the major steels of mild, high tensile, HY80, and HY100 (described in Section 3.2) used in the construction of hull non-nuclear structures for surface combatant ships in the United States Navy.

CAN WELD JOINT BE ELIMINATED?

This decision junction asks the question of whether or not a weld joint can be eliminated.

IF YES - ELIMINATE WELD JOINTS BY USING STANDARD SECTIONS AND FORMING

There are many standard preformed sections available and should be used whenever possible. Using standard sections is cheaper than welding many individual parts or employing other fastening methods.

IF NO - WELDABILITY

Weldability is a factor to be considered in the selection of a welding process. Certain welding processes are limited in terms of what type of steels they can be used on. Figure 21 illustrates the weldability of mild, high tensile, HY80, and HY100 steels. Mild, high tensile, and HY80 steel can be welded with any of the SMAW, GMAW, SAW, and FCAW processes. However, if HY100 steel is selected that disqualifies the FCAW process because it has no service proven electrodes for U.S. Navy applications to weld this

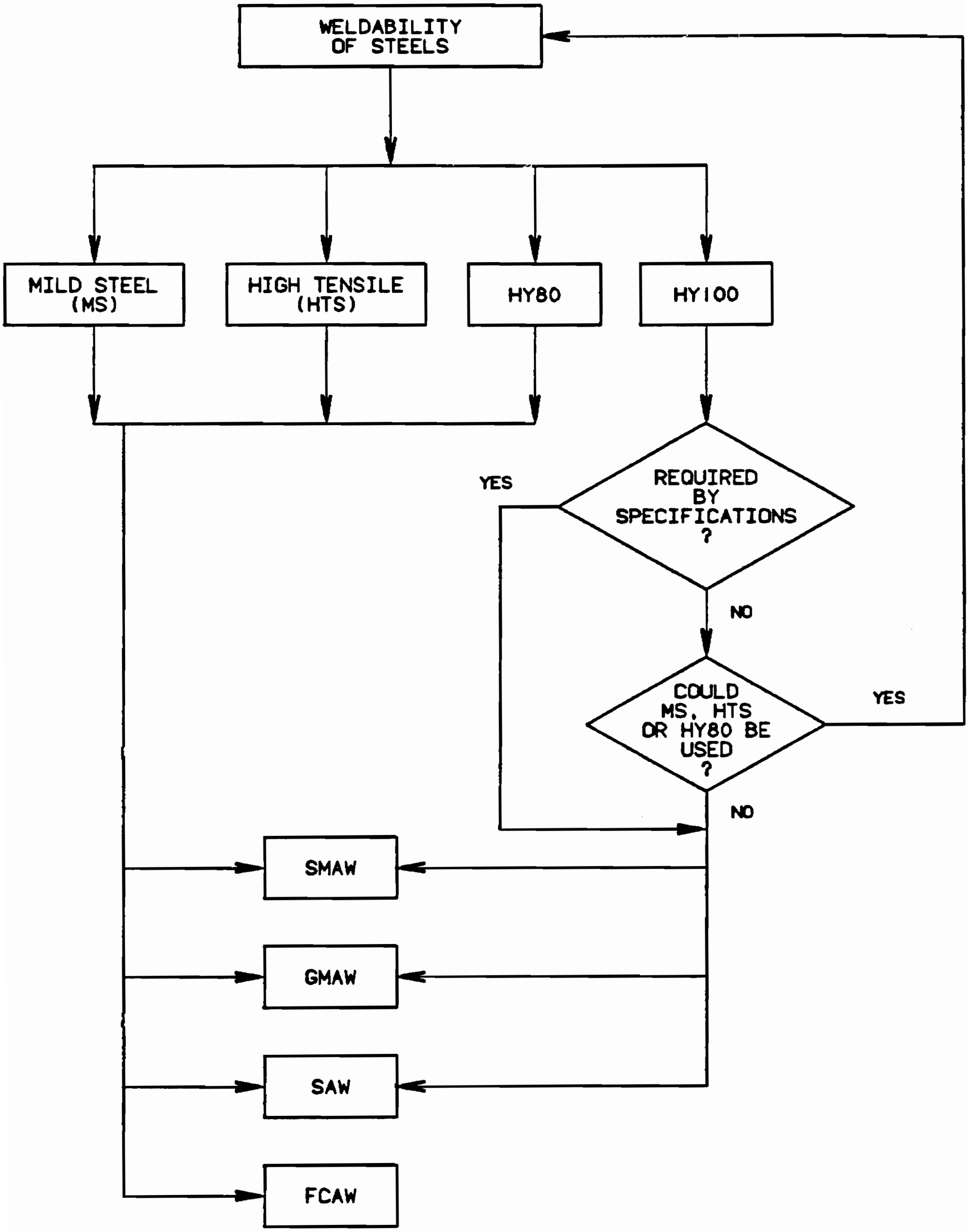


Figure 21. Weldability Flow Chart.

steel. If a material is very limited in terms of weldability, the designer may elect to go back and choose another material as shown in Figure 20.

SELECT WELD JOINT

There are five basic types of joints for weld design: (1) butt, (2) corner, (3) tee, (4) lap, and (5) edge. Weld joint details are based on the Mil-Std-22 specification [2]. The selection of a weld joint type is dependent on load requirements (see Section 3.4). Figure 22 illustrates that the design engineer will select one of the five basic types of weld joints based on loading conditions from the Mil-Std-22 specification [2].

WELDING POSITION

The welding position affects the speed by which welding can be done and can disqualify the selection of a welding process. Welding speed in the downhand position is the fastest, followed by the vertical position and then the overhead position. Therefore, weld joints should ideally be designed for the downhand position. Else, the vertical position should be the next choice followed by the overhead

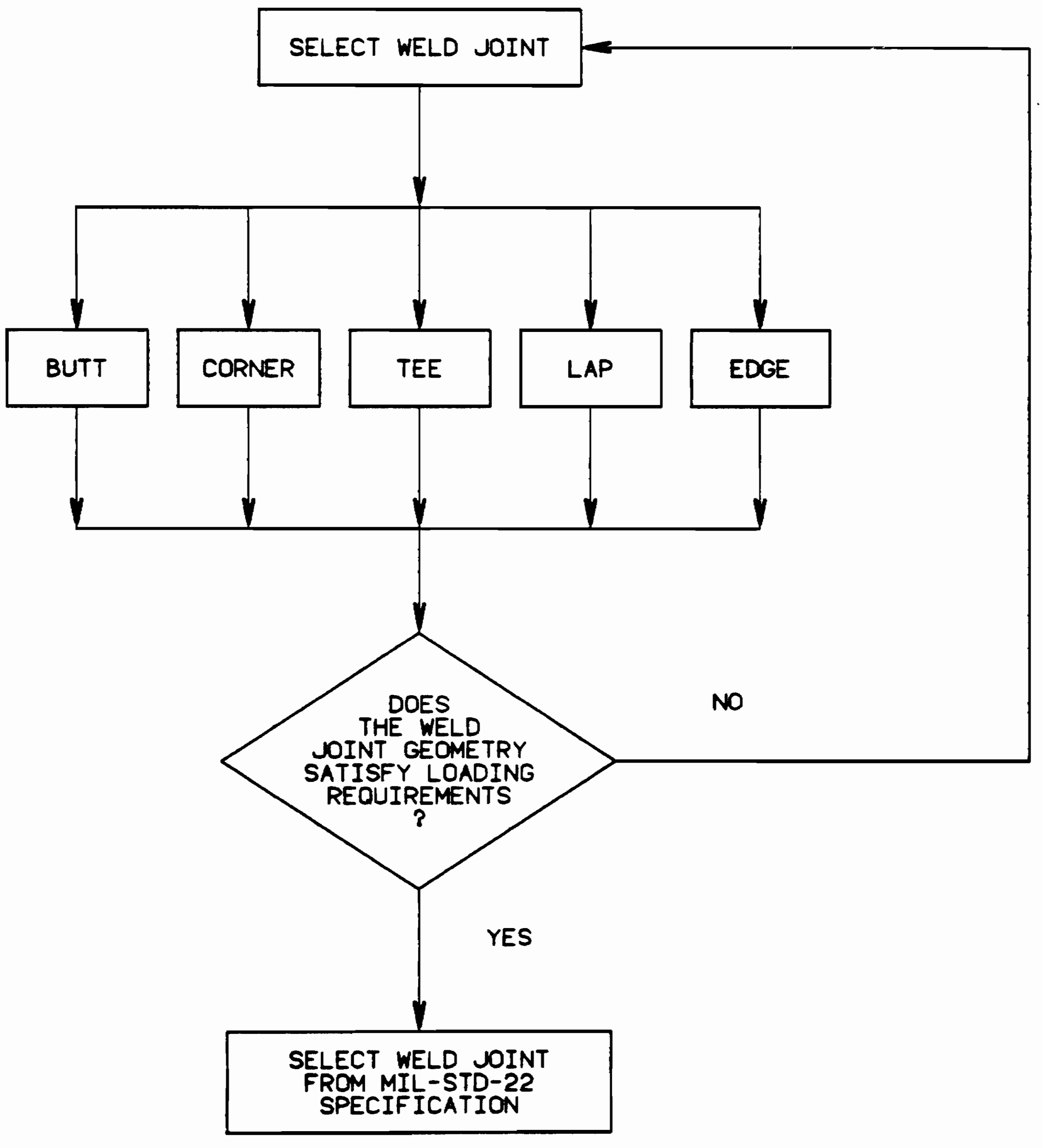


Figure 22. Select Weld Joint Flow Chart.

position as third option. Figure 23 illustrates a decision framework for the selection of a weld process. The SMAW, GMAW, and FCAW processes can be used in all welding positions. The SAW process, however, can only be used in the downhand position because this process has a high weld deposit rate which creates a large molten pool of weld slag that can run out of the weld joint in the vertical and overhead positions. If the weld joint is moved to accommodate a more efficient welding position then the designer needs to analyze the possible new loading condition on the weld joint as shown in Figure 20.

ACCESSIBILITY

Accessibility is a high priority in weld joint design. A design in a difficult to reach location may limit the different welding processes that can be used. Automatic (A) processes have the greatest welding speeds but require maximum accessibility. The semi-automatic (SA) processes are slower than the automatic ones, but faster than the manual process of SMAW. Semi-automatic processes requires at least average accessibility. Figure 24 illustrates how weld accessibility impacts the selection of a welding process.

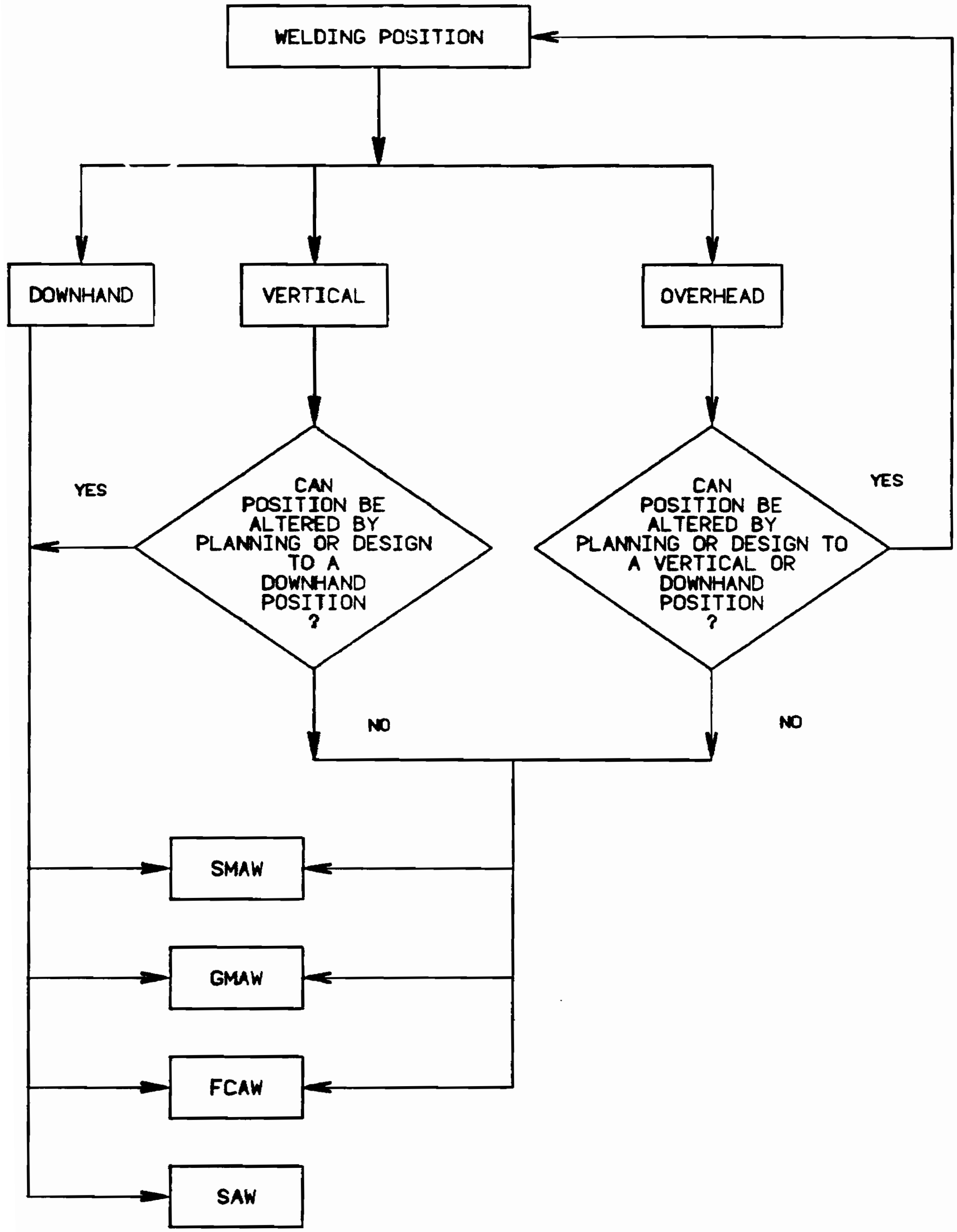


Figure 23. Welding Position Flow Chart.

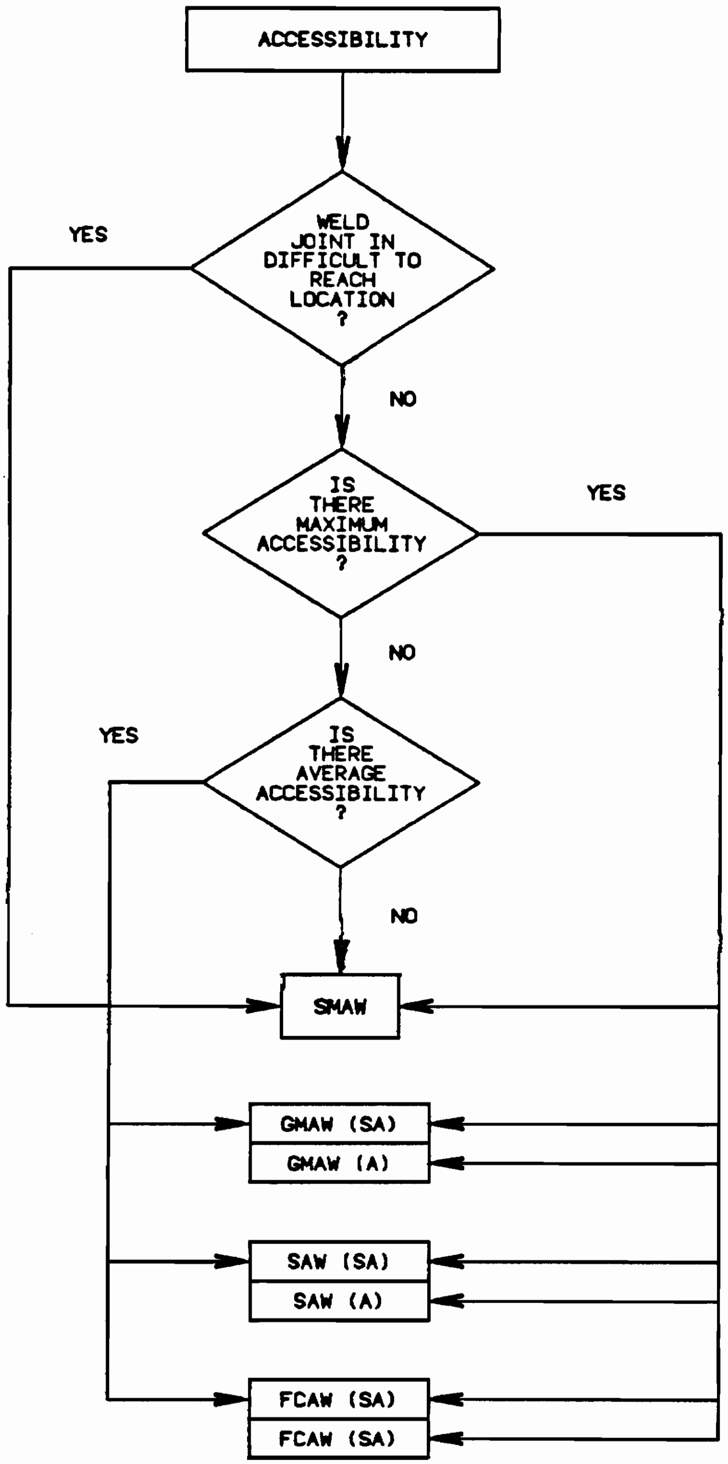


Figure 24. Accessibility Flow Chart.

IS THERE MORE THAN ONE WELDING PROCESS THAT SATISFIES RESTRICTIONS?

This decision junction examines components of weldability, welding position, and accessibility to determine if there is more than one welding process available for selection.

IF NO - WELDING PROCESS

This indicates that accessibility was a problem. All welding processes except the SMAW process were eliminated from selection. Therefore, the system selects the SMAW process and stops.

IF YES - TRADE-OFF ANALYSIS

Trade-off analysis is an evaluation of the SMAW, GMAW, SAW, and FCAW processes. This evaluation will aid the design engineer in determining the most cost-effective welding process.

The manufacturing factors of deposition rate, operator factor, deposition efficiency, welding position, and accessibility are analytically evaluated in a series of graphs and tables. The design engineer with this information can measure the different welding processes performance and select the most cost-effective weld process for the job currently being designed.

The cost relationship between manufacturing factors of deposition rate, operator factor, welding position, and accessibility are analytically evaluated by the labor cost equation [7].

Labor Cost($) = LOFC($/hr) [Vol(in3) x Density(lb/in3)] x [1/DR(lb/hr) x 1/OF] x EF

where:

LOFC($/hr): Labor overhead and fringes cost (overhead includes equipment amortization and facilities charges) - $15.00/hr (constant)

Vol(in3): Weld Volume

Density(lb/in3): Material Density - Steel 0.283 lb/in3

DR(lb/hr): Deposition Rate

OF: Operator Factor

EF: Experience Factor

- Unexperience welder (1)
- Experience welder (1.333)

The use of the experience factor in the labor cost equation permits the welder's skill to be a factor in the trade-off analysis. An inexperienced welder usually has minimal training. This class of welders would be selected for welding in the downhand position and average or better weld joint accessibility. The use of inexperienced welder outside these boundries would cost more in the long run due to lower quality work. The experienced welder is selected for welding done in the vertical and overhead positions with minimum accessibility. is at a minimum.

Figure 25 presents the labor cost equation for welding a 3/4 inch fillet of 10 feet long at varied deposition rates, and operator factors (from Table 2). These curves demonstrate the effects of different manufacturing factors on the selection of a weld process, which are summarized as follows:

1. Process selection and deposition rates are most effective in controlling welding cost.
2. Automatic welding processes should be used if possible due to their deposition rate (DR) and operator factor (OF) impacts on the labor cost equation.

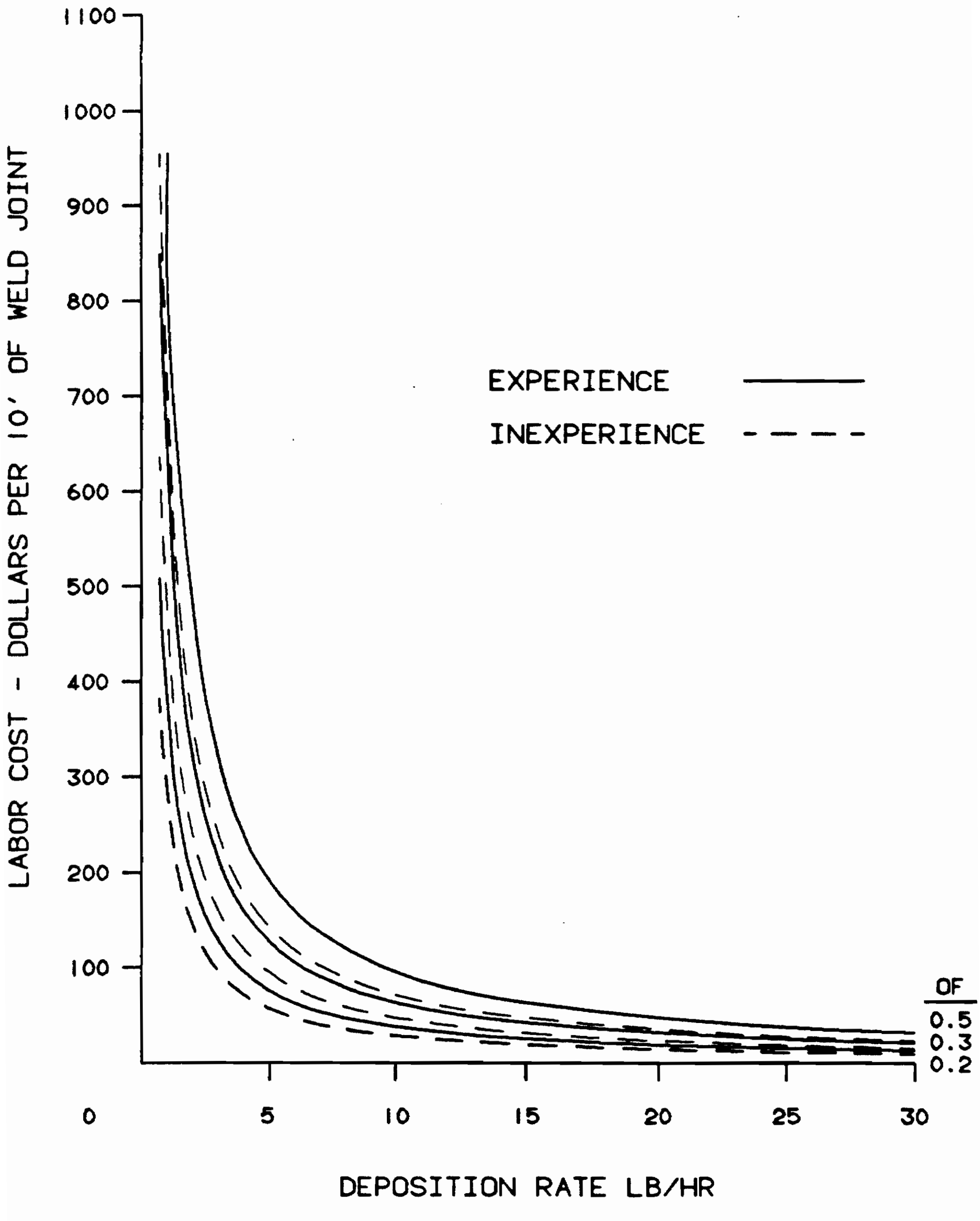


Figure 25. Graphic Representation of the Labor Cost Equation for Various Deposition Rates.

3. Welding position greatly affects the deposition rate of the process.
4. Operator factor can be improved through process selection.
5. Design can improve the operator factor by:
   A. Planning and positioning work to minimize physical strain on welders.
   B. Placing weld joints in accessible areas and, if possible, in the flat or downhand position.

Table 8 and 9 provides obtainable results that evaluate the manufacturing factors of operator factor, deposition efficiency, and welding position in an effort to compare costs of deposited filler metal using the SMAW, GMAW, SAW, and FCAW processes. Included in the test was the cost of labor, overhead and fringes cost ($20.00/hr for Table 8 and $15.00/hr for Table 9).

Table 8 demonstrates that process selection and welding position affect the costs of a weld joint. It has been found that horizontal welds using the SAW (A) process

Table 8. Welding Process Cost Comparisons [33].

PROCESS	POSITION	ELECTRODE $/LB	LABOR $/LB	GAS $/LB	FLUX $/LB	TOTAL $/LB
SMAW	V	1.18	22.98	---	---	24.16
SMAW	H	0.66	13.40	---	---	14.06
FCAW W/CO2 (SA)	V	1.47	7.05	0.55	---	9.07
GMAW (SA)	H	0.70	5.34	0.42	---	6.46
FCAW W/CO2 (SA)	H	1.35	4.04	0.11	---	5.50
SAW	H	0.81	0.80	---	0.42	2.03

NOTE: RATES, ARE FOR WELDING A 5/16 INCH FILLET HORIZONTAL AND A 1/4 INCH FILLET VERTICAL. SAW (A) INFORMATION WAS ESTIMATED FROM VARIOUS SOURCES.

Table 9. Welding Process Cost Comparisons [7].

PROCESS	POSITION	LABOR $15/HR	MATERIAL $	COST $/LB
SMAW	V-OH	1,767	30	49.90
SMAW	H	784	28	20.30
GMAW	ALL	135	82	5.44
SAW	H	60	95	4.62

NOTE: RATES ARE BASED ON WELDING A DOUBLE V-BUTT THAT IS TWO INCHES THICK, LINEAR LENGTH OF 10 FEET, AND A 40 DEGREE INCLUDED JOINT ANGLE.

cost 63% less than the FCAW (SA) with CO_2 shielding gas process, 69% less than the GMAW (SA) process, and 86% less than the SMAW process. Vertical welds using the FCAW (SA) with CO_2 shielding gas process cost 62% less than the SMAW process welds.

Sometimes the weld process with the highest deposition rate and operator factor is not the most cost-effective weld process. When considering the time it takes to set up the equipment required to perform the welding task, a less efficient weld process may be more cost-effective. Figure 26 illustrates the cost per foot fron the start-up for various welding processes in the horizontal position. Figure 27 shows these costs for the vertical position.

To develop the graphs of figures 26 and 27 the following data and equations were used:

Set-up Time:	Manual Process	30 min
	Semi-Automatic Process	40 min
	Automatic Process	2 hrs

(Assuming one man)

Volume(in^3/ft) x Density(lb/in^3) = ______ lb/ft

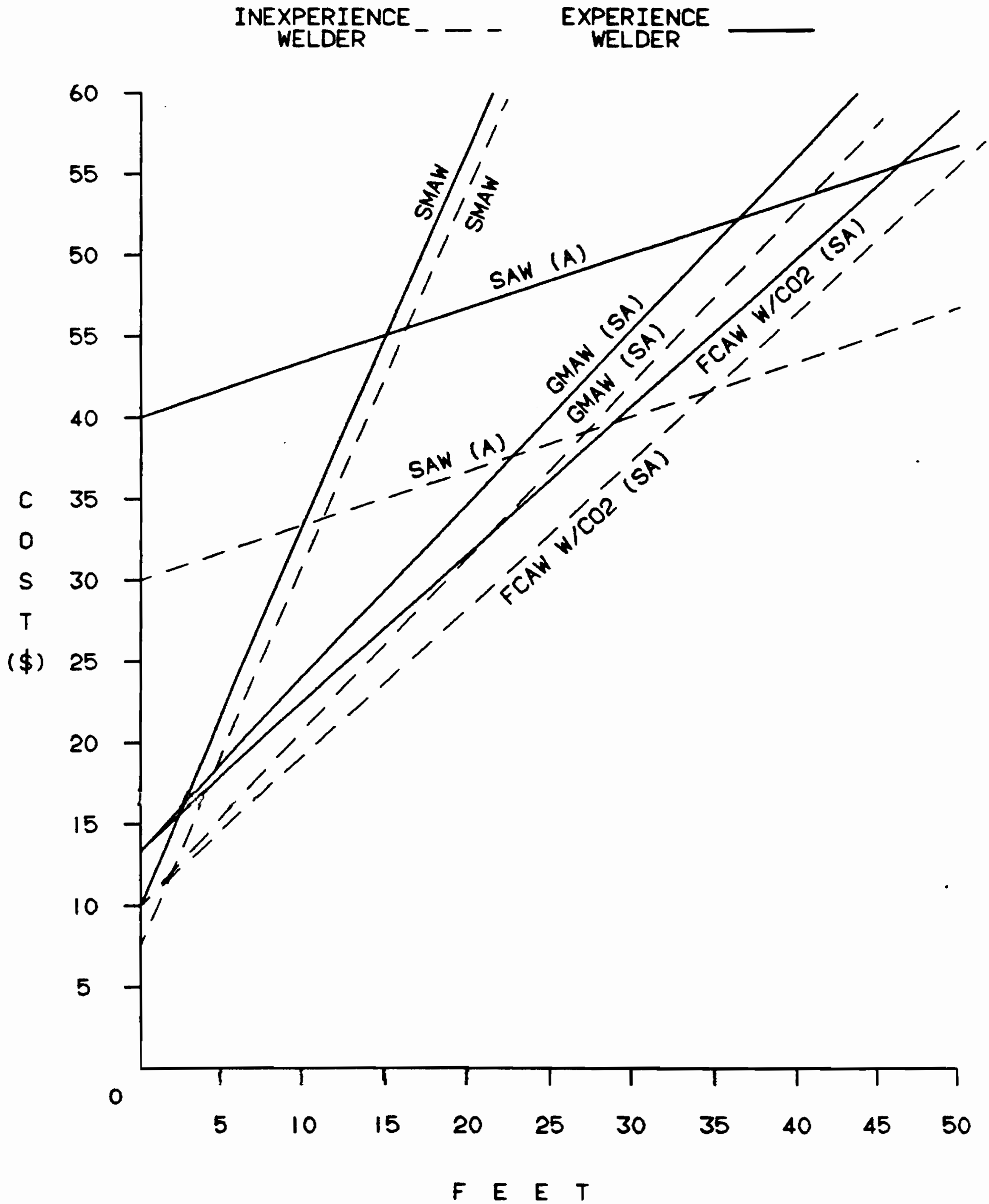


Figure 26. Cost Per Foot for Various Welding Process in the Downhand Position From Start-up. (Cost Includes Set-up Time) Weld Joint is a 5/16 Single Fillet.

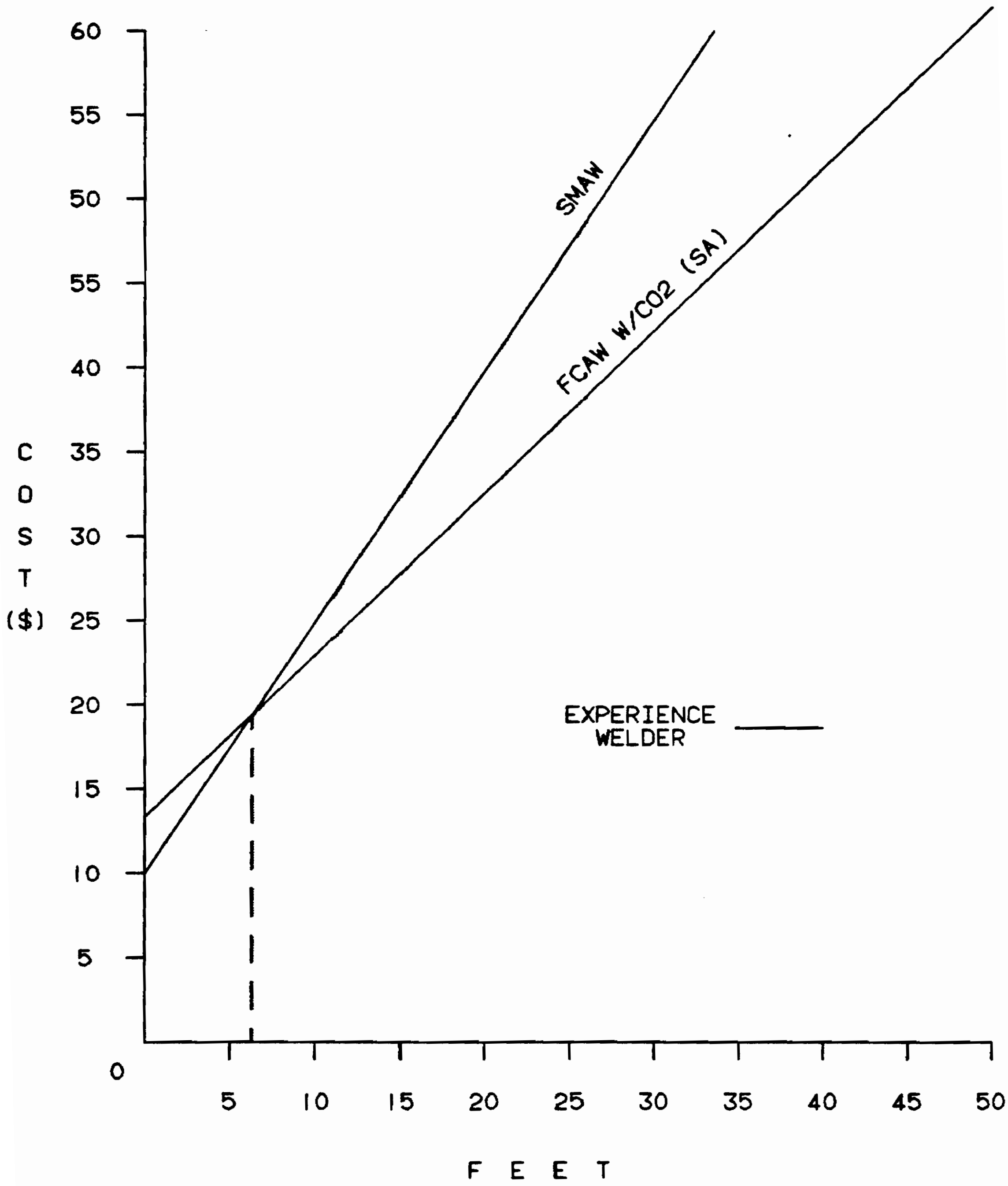


Figure 27. Cost Per Foot For Various Welding Process in the Vertical Position From Start-up. (Cost Includes Set-up Time) Weld Joint is a 1/4 Single Fillet.

where:

Volume(in3/ft): Weld volume - 5/16 single fillet (horizontal)
- 1/4 single fillet (vertical)

Density(lb/in3): Material density - steel 0.283 lb/in3

____lb/ft x Welding Process ($/lb) (Table 8) = ____ $/ft

Figures 26 and 27 demonstrate that because of set-up time the SMAW process with its low deposition rate, low operator factor, low deposition efficiency, and high welding cost can be more cost-effective for small linear length jobs than the higher efficient semi- and automatic-welding processes. The same holds true with the SAW (A) process with its low cost per foot rating. Because of the SAW set-up time, this process should be used for weld joints that are very long in length.

Figure 28 illustrates the decision framework for the trade-off analysis. Eligible weld processes are determined for the trade-off analysis based on restrictions from previous components of weldability, welding position and accessibility. An inexperience or experience welder is determined based on welding position and weld joint accessibility. From the labor cost equation, the costs of all eligible weld processes are obtained. Welding processes are ranked lowest to highest based on these costs. If the weld joint is to be welded overhead, the framework selects the top ranked welding process which would be either GMAW or FCAW except in the case of very small jobs (for less than 2 feet of linear weld, SMAW would be appropriate). If the weld joint requires welding in the downhand or vertical position, the length of the weld joint must be first determined. The selection is then based on the results determined by the equations reflecting set-up time and linear length of weld (see Figures 26 and 27).

CAN THE WELD JOINT DESIGN BE OPTIMIZED?

This decision junction asks the question whether or not the weld joint design can be optimized. Only fillet and butt weld joint can be optimized.

IF NO - SELECTION OF WELD PROCESS FINISHED

Then the weld process selected from the trade-off

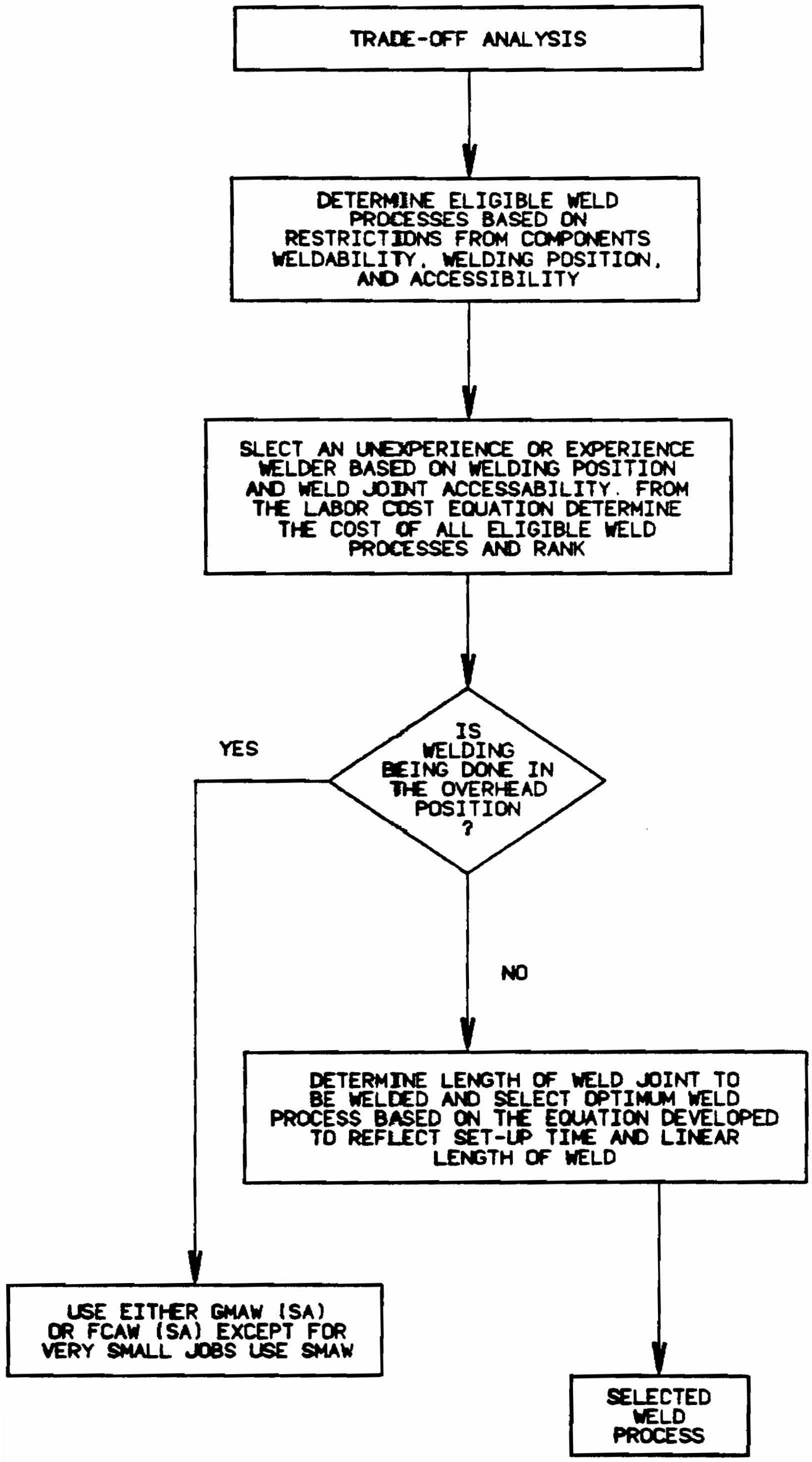


Figure 28. Trade-off Analysis Flow Chart.

analysis and the weld joint selected from Mil-Std-22 specification [2] are used.

IF YES - OPTIMIZATION OF THE WELD JOINT DESIGN

Design engineers for U.S. Navy ship construction select weld joint details from the Mil-Std-22 specification [2]. The joints listed in this military specification are prequalified for SMAW, GMAW, SAW, and FCAW processes. However, to take advantage of the GMAW, SAW, and FCAW processes superior capabilities, modifications should be made to the joint design for economical and efficiency reasons.

Figure 29 is the decision framework for the optimization of the weld joint design. If the SMAW process is selected from the trade-off analysis, then the most optimum weld joints are selected from the Mil-Std-22 specification. If the weld process selected from the trade-off analysis is SAW, GMAW, or FCAW with CO_2 shielding gas and the weld joint to be welded is a fillet or butt weld, then the weld joint can be modified. Fillet welds can be

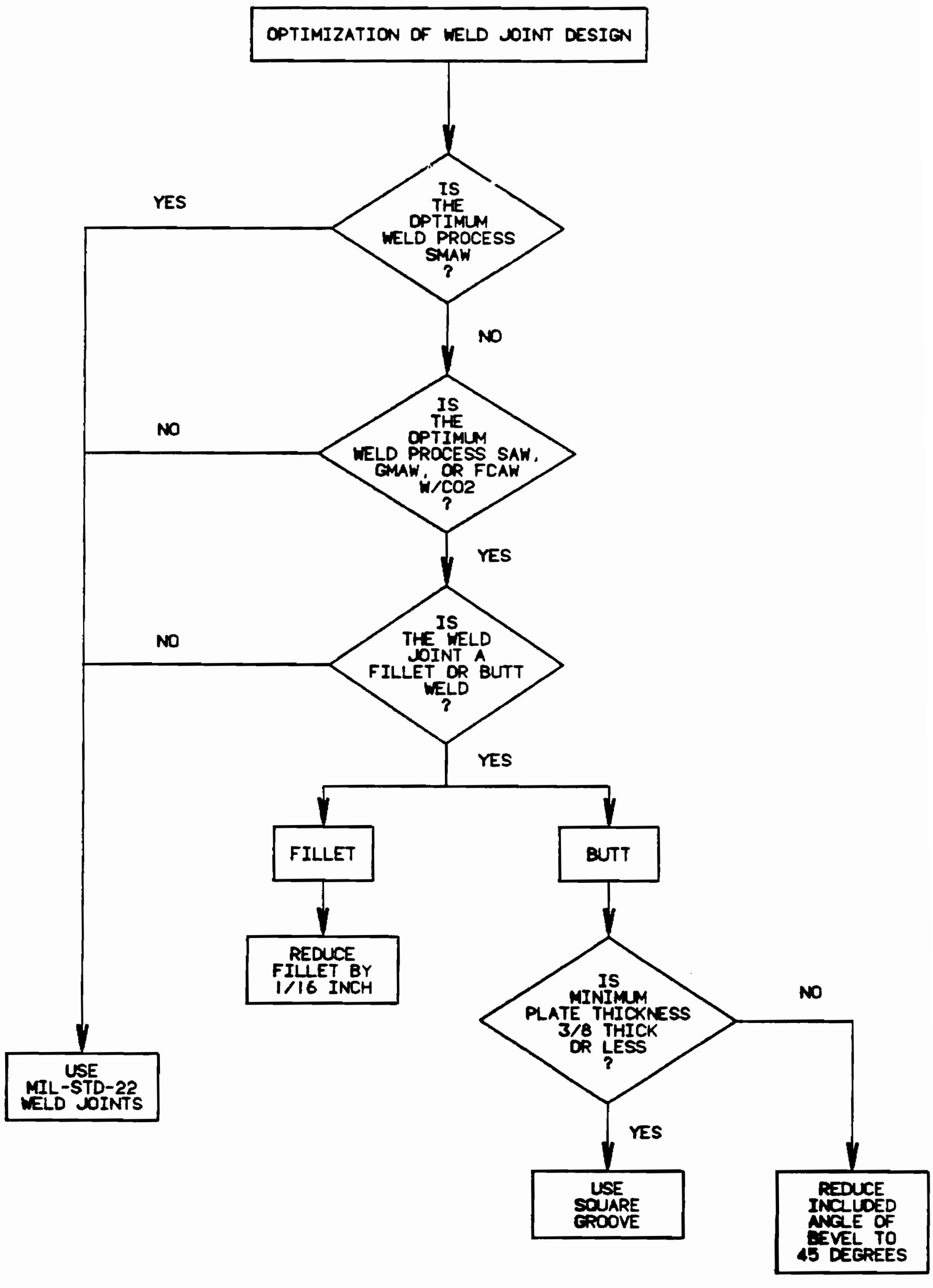


Figure 29. Optimization of Weld Joint Design Flow Chart.

reduced because traditionally design engineers designed fillets under the assumption that the fillet weld penetrates just to the corner of the joint. The SAW, GMAW, and FCAW with CO_2 shielding processes, however, provide deeper penetration thus providing an effective throat depth of 20% to 30%. This increased penetration allows for smaller fillet welds, but conservatively the fillet weld will be reduced by only 1/16 of an inch and the size of the fillet can not be smaller than 1/8 of a inch. Butt welds can, also, be modified using the SAW, GMAW, and FCAW with CO_2 shielding gas processes. These processes have smaller diameter wires which allow for a smaller groove included angle. Additionally, these processes allow for superior penetration capabilities eliminating the groove design for plates under 3/8 inch in thickness or reducing the included angle from 60 degrees (typically in Mil-Std-22) to 45 degrees.

5.4 SYSTEM EXAMPLES

A set of examples are presented to demonstrate the feasibility of the developed system.

5.4.1 EXAMPLE NO.1

Stiffeners are to be designed to support a high tensile steel (HTS) watertight structural bulkhead. The length of each stiffener is from deck to deck or 10 feet.

RECOGNITION OF A NEED

Stiffeners need to be attached to the bulkhead and welding is the most cost-effective method for this process.

DETERMINE LOAD CONDITIONS, SERVICE REQUIREMENTS AND ANALYZE

The bulkhead is designed to provide watertight integrity. This bulkhead, based on ship specifications, has a design hydrostatic head of so many feet. The stiffeners are sized based on their spacing on the bulkhead. The stiffener size has been determined to be a 4x4x3/8 angle (L).

SELECT STEEL

The steel selected is high tensile steel (HTS) based on the stress levels in the 4x4x3/8 angle (L).

CAN WELD JOINT BE ELIMINATED? - NO

WELDABILITY

The weldability of high tensile steel (HTS) is that all four welding processes, SMAW, GMAW, SAW, and FCAW can be selected.

SELECT WELD JOINT

The weld joint selected to weld the 4x4x3/8 angle (L) (HTS) stiffener to the high tensile steel (HTS) bulkhead is a 5/16 double fillet weld. The size of the fillet weld is based on the web thickness of the stiffener.

WELDING POSITION

The stiffeners are to be welded on the bulkhead in the downhand welding position and upon completion the bulkhead would be raised to the vertical position for final installation. Eligible welding processes for selection after this factor are SMAW, GMAW, SAW, and FCAW.

ACCESSIBILITY

The panel stiffeners have maximum accessibility to deposit the double fillet weld with no obstructions to interfere with the welding operation. Eligible welding processes for selection after this factor are SMAW, GMAW (A), GMAW (SA), SAW (A), SAW (SA), FCAW (A), and FCAW (SA).

IS THERE MORE THAN ONE PROCESS THAT SATISFIES RESTRICTIONS? YES

The trade-off is performed for the SMAW, GMAW (A), GMAW (SA), SAW (A), SAW (SA), FCAW (A), and FCAW (SA) processes. Although the GMAW (A), SAW (SA), and FCAW (A) processes are eligible, it is common practice to use the GMAW and the FCAW processes in the semi-automatic mode and the SAW process in the automatic mode. The labor cost equation is used to compare labor costs among the eligible welding processes. The deposition rates of the eligible welding processes are determined from Table 1, lists the deposition rate versus the welding position. The deposition rates for the downhand position for the eligible weld processes are as follows:

1. SMAW	-	6 lbs/hr
2. GMAW (SA)	-	20 lbs/hr
3. FCAW (SA)	-	20 lbs/hr*
4. SAW (A)	-	55 lbs/hr

* FCAW (SA) uses CO_2 shielding gas.

The following are the labor costs of SMAW, GMAW (SA), FCAW (SA), and SAW (A) associated with their deposition rates, and operator factors. An unexperience welder is selected because the welding position is downhand and there weld joint accessibility is maximum.

1. SAW (A)	-	$0.90 per 10 feet
2. GMAW (SA)	-	$4.15 per 10 feet
3. FCAW (SA)	-	$4.15 per 10 feet
4. SMAW	-	$20.73 per 10 feet

The length of the fillet weld to be welded is 10 feet. Using Figure 26 (downhand position) to compare GMAW (SA) to SAW (A), it is determined that GMAW (SA) is more cost effective. GMAW (SA) is next compared to FCAW (SA) and it is determined that FCAW (SA) is more cost effective. FCAW (SA) is next compared to SMAW and it is determined is more cost effective. Therefore, the FCAW (SA) process with CO_2 shielding gas is the most optimum process for this situation.

CAN WELD JOINT BE OPTIMIZED? - YES

OPTIMIZATION OF THE WELD JOINT DESIGN

The weld joint selected in the component of weld joint was a double fillet weld. Because of the increased penetration of the selected FCAW (SA) with CO2 shielding gas, this joint can be optimized. The new fillet size can be reduced 1/16 of an inch to 1/4 of an inch.

REMARKS

In this instance the conclusion lead to the selection of the FCAW (SA) with CO2 shielding gas process as the most optimum process to use in welding the double fillet weld attaching the panel stiffener. There is a cost savings of 7.5% in using the FCAW (SA) process over GMAW (SA), 38% savings over the SMAW process, and a 42% savings over the highest deposition rate process of SAW (A). The system allowed the fillet size to be reduced. This decrease in the fillet size from 5/16 of an inch to 1/4 of an inch reduces weld volume by 36%.

5.4.2 EXAMPLE NO.2

The hole cuts in the structure of a completed innerbottom unit need coamings.

RECOGNITION OF A NEED

Coamings need to be welded into the hole cuts in HY80 steel structure to reduce stress concentrations.

DETERMINE LOAD CONDITIONS, SERVICE REQUIREMENTS AND ANALYZE

The size of the coaming is used to replace the area of hole in the structure. The coaming size is determine to be 3 inches wide by 1/4 inch thick.

SELECT STEEL

Ship specifications require that coaming material match the material being cut out. Therefore, the coamings are to be of HY80 steel material.

CAN WELD JOINT BE ELIMINATED? - NO

WELDABILITY

The weldability of HY80 is that all four welding processes, SMAW, GMAW, SAW, and FCAW can be selected.

SELECT WELD JOINT

The coaming is to be centered in the structure. Therefore, a double fillet weld would be used. The fillet size was determined to be 3/16 of an inch.

WELDING POSITION

The holes were cut in the vertical structure. Therefore, when welding coaming in the holes the welding position is vertical. Eligible welding processes for selection after this factor are SMAW, GMAW, SAW, and FCAW.

ACCESSIBILITY

The holes were cut in a finished unit. The accessibility is at a minimum. This indicates that there are major obstructions interfering with the welding operation. Eligible welding processes after this component is SMAW.

IS THERE MORE THAN ONE PROCESS THAT SATISFIES RESTRICTIONS? NO

The SMAW process is selected.

REMARKS

Due to accessibility, the weld process selected is SMAW. In such cases, communication between design and manufacturing is needed. Could these holes have been cut earlier to avoid restricted accessibility? Is more planning needed? A dialog between design and manufacturing is worth the effort to find out how parts are being manufactured.

5.4.3 EXAMPLE NO.3

A strength deck for a ship is to be designed. The width of this deck is 80 feet and the length of the deck is 500 feet. This deck also has been designated ballistic.

RECOGNITION OF A NEED

Steel plates are usually available in 12 feet by 40 feet sections. Therefore, to make up the 500 feet length there will be a number of transverse seams 80 feet wide.

DETERMINE LOAD CONDITIONS, SERVICE REQUIREMENTS AND ANALYZE

Ship specifications require that the ballistic deck be 81.6 lbs/ft2 (two inches thick) and be made of HY100 steel.

SELECT STEEL

Steel HY100 is selected per ship specifications.

CAN WELD JOINT BE ELIMINATED? - NO

WELDABILITY

HY100 is required by ship specification and therefore mild (MS), high tensile (HTS), or HY80 steel could not be used. The weldability factor of HY100 steel results in the elimination of the FCAW process from selection. Eligible welding processes are SMAW, GMAW, and SAW processes.

SELECT WELD JOINT

The weld joint selected for the welding of the transverse seam is the butt weld joint. The butt weld joint selected is the B2V.3 designation per specification Mil-Std-22 [2] and is consistent with Table 7. The butt joint is a double V with a 60 degree included bevel angle.

WELDING POSITION

The transverse seam will be welded in the downhand or flat position. Eligible welding processes based on this factor are SMAW, GMAW, and SAW.

ACCESSIBILITY

The transverse butt joint has maximum accessibility with no obstructions to interfere with the welding operation. Eligible welding processes after this factor are SMAW, GMAW (A), GMAW (SA), SAW (A), and SAW (SA).

IS THERE MORE THAN ONE PROCESS THAT SATISFIES RESTRICTIONS? YES

TRADE-OFF ANALYSIS

The trade-off analysis is performed for the SMAW, GMAW (SA), and SAW (A) processes. Though the GMAW (A) and SAW (SA) processes are eligible, it is a common practice to use the GMAW and FCAW in the semi-automatic mode and the SAW process in the automatic mode. The labor cost equation is then used. The deposition rates of eligible welding processes are determined from Table 1. The deposition rates for the downhand position for the eligible weld processes are as follows:

1. SMAW - 3.1 lbs/hr
2. GMAW (SA) - 6.6 lbs/hr
3. SAW (A) - 12.0 lbs/hr

The following are the labor costs for SMAW, GMAW (SA), and SAW (A) processes. An inexperienced welder is selected because the welding position is downhand and weld joint accessibility is maximum.

1. SAW (A) - $294.09 per 10 feet
2. GMAW (SA) - $534.71 per 10 feet
3. SMAW - $1138.42 per 10 feet

The length of the transverse weld joint to be welded is 80 feet. Using the set up and linear length equations, the SAW (A) cost is $4387.87/80 feet which is less than the GMAW (SA) cost of $5129.58/80 feet. Therefore, the SAW (A) process is the most optimum weld process for this situation.

CAN THE WELD JOINT DESIGN BE OPTIMIZED? - YES

OPTIMIZATION OF THE WELD JOINT DESIGN

The weld joint selected was a butt joint. The butt weld joint is a B2V.3 designation of Mil-Std-22 specification [2] with a double V and a 60 degree included bevel angle. Because the SAW (A) process was selected, this joint can be optimized. The new butt joint included bevel angle will be 45 degrees.

REMARKS

In this instance the conclusion led to the selection of the SAW (A) process as the most optimum process to use in welding the transverse seam. There is a cost savings of 15% in using the SAW (A) process over GMAW (SA), 80% over the SMAW. The system allowed the bevel angles of the butt joint to be optimized in the design cycle, so that the included bevel angle would be reduced before going to manufacturing at which point it would have been too late to change. There is weld volume savings with the reduced included bevel angle of 45 degrees.

CHAPTER 6

CONCLUSIONS AND FUTURE WORK

6.1 CONCLUDING REMARKS

The developed system demonstrates that integrating the manufacturing factors into the design cycle to select a welding process is a cost-effective method resulting in reduced costs in the product life cycle. Welding is often a bottleneck in manufacturing. The use of automation for welding has not kept pace with other manufacturing processes such as machining. The developed system makes optimal decisions that are suitable for welding automation. Such optimization is used to economically produce a weldment. Therefore, this system increases the manufacturing knowledge of design engineers, improves designs and enhances control of welding productivity and manufacturing costs.

The developed system emphasizes that manufacturing is an important part in the cost of the product life cycle. The weldability of the steel, positioning of the weld joint as well as the weld's accessibility can greatly affect efficiency and the selection of a weld process. The selection of a weld process and welding position directly impact the costs of a weld joint. It has been found that horizontal welds using the SAW (A) process can cost 63% less than the GMAW (SA) process, and 86% less than the SMAW process. Vertical welds using the FCAW (SA) with CO2 shielding gas process can cost 62% less than the SMAW process welds. The determination of a weld process in the design cycle may allow the design engineer to reduce fillet welds and reduce included bevel angles on butt welds. If the weld process is unknown in the design cycle, the design engineer would design for the most conservative SMAW weld process.

The welding of a ship's hull structure accounts for about 30% of the total man-hours required for the completion of the entire hull structure [34]. Typically, about 75% of welds are fillet welds in ship hull construction [16]. Therefore, fillet welds account for approximately 22.5% of the total labor cost in the construction of a ship's hull. By decreasing the fillet size by 1/16 of an inch from 5/16 of an inch to 1/4 of an inch, a 36% reduction in weld volume can be achieved. The developed system provides for optimization of fillet weld sizes when the automatic weld processes are used to achieve large cost savings in the welding of a hull structure.

Butt joints can be assumed to roughly make up the other 25% of ship hull welds. The costs for these welds would be approximately 7.5% of the total labor cost for constructing a ship's hull. By optimizing the included angle of the butt joint groove angle from 60 degrees to 45 degrees for the automatic welding processes, a 1/2 inch thick plate with a single groove design has 71% less weld volume. The developed system optimizes butt weld joints to produce large cost savings in the welding of a hull structure.

Finally, the developed system can be used to open communications between design and manufacturing personnel. The system makes both groups of engineers more sensitive to the other's needs. This system when properly applied is a cost-effective method directing the focus of two vital disciplines of design and manufacturing on a common objective.

6.2 FUTURE WORK

The next logical step in the expansion of the developed system configuration is operational testing. This testing would be performed as close as possible to a true working environment. The evaluation of this testing would be used to resolve such questions as how the data will be given to the shop. For example, an extra weld process designation would be added to the weld joint symbol on the working drawing so that this data can be forwarded to manufacturing. Therefore, this type of testing is more meaningful and the effectiveness of the evaluated system assumes more significance.

Future work on the developed system is to develop an expert system to capture and disseminate logic about welded structure design. The expert system design would utilize a knowledge base containing decision logic in the form of rules along with facts which define optimum welding processes under various circumstances. User supplied information such as material type, weld joint, accessibility, and welding position would allow the system to provide a description of the optimum joint with an optimum welding process. The goal is to provide manufacturing "intelligence" as an integral part of the design process.

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APPENDIX

TERMS AND DEFINITIONS

Arc-Time: The length the arc is maintained in making an arc weld.

Arc Welding: A group of welding processes wherein coalescence is produced by heating with an arc or arcs, with or without the application of pressure and with or without the use of filler metal.

Automatic Welding (A): Welding with equipment which performs the entire welding operation without constant observation and adjustment of the controls by an operator. The equipment may or may not perform the loading and unloading of the work.

Average Accessibility: Indicates that there can be minor obstructions, but there must be at least 3 inches abreast, and 6 inches forward, back, and vertical of clear space around the weld joint.

Base Metal: The metal to be welded or cut.

Bevel: An angular type of edge preparation.

Bevel Angle: The angle formed between the prepared edge of a member and a plane perpendicular to the surface of the member.

Butt Joint: A joint between two members lying approximately in the same plane.

Butt Weld: A weld in a butt joint.

Coalescence: The growing together, or growth into one body, of the base metal parts.

Corner Joint: A joint between two members located approximately at right angles to each other in the form of an L.

Deposited Metal: Filler metal that has been added during a welding operation.

Deposition Efficiency: The ratio of the weight of deposited metal to the net weight of electrodes consumed, exclusive of stubs.

Deposition Rate: The weight of metal deposited in a unit of time.

Downhand: The position of welding wherein welding is performed from the upper side of the joint and the face of the weld is approximately horizontal.

Edge Joint: A joint between the edges of two or more parallel or nearly parallel members.

Edge Preparation: The contour prepared on the edge of a member for welding.

Face of Weld: The exposed surface of a weld on the side from which welding was done.

Filler Metal: The metal to be added in making a welded joint.

Fillet Weld: A weld of approximately triangular cross-section joining two surfaces approximately at right angles to each other in a lap joint, tee joint, or corner joint.

Flat Position: The position of welding wherein welding is performed from the upper side of the joint and face of the weld is approximately horizontal.

Flux: Material used to prevent, dissolve or facilitate removal of oxides and other undersirable substances.

Flux Cored Arc Welding (FCAW): An arc welding process wherein coalescence is produced by heating with an arc, between a continuous filler metal electrode and the work. Shielding is obtained from a flux contained within the electrode. Additional shielding may or may not be obtained from an externally supplied gas or gas mixture.

Gas Metal Arc Welding (GMAW): An arc welding process wherein coalescence is produced by heating with an arc between a continuous filler metal electrode and the work. Shielding is obtained entirely from an externally supplied gas, or gas mixture.

Groove: The opening provided for a groove weld.

Groove Angle: The total included angle of the groove between parts to be joined by a groove weld.

Horizontal Position:

Fillet Weld - The position of welding wherein welding is performed on the upper side of an approximately horizontal surface and against an approximately vertical surface.

Groove Weld - The position of welding wherein the axis of the weld lies in an approximately horizontal plane and the face of the weld lies in an approximately vertical plane.

Joint: The location where two or more members are to be joined.

Joint Design: The joint geometry together with the required dimensions of the welded joint.

Joint Geometry: The shape and dimensions of a joint in cross-section prior to welding.

Lap Joint: A joint between two overlapping members.

Manual Welding: Welding wherein the entire welding operation is performed and controlled by hand.

Maximum Accessibility: Indicates that there are no obstructions to interfere with the welding operation and at least 24 inches abreast, 12 inches forward and back, and 48 inches vertically of clear space in way of the weld joint.

Minimum Accessibility: Indicates that there are major obstructions interfering with the welding operation, and that there is less than 3 inches abreast, 6 inches forward, back, vertically of clear space to weld the joint.

Overhead Position: The position of welding wherein welding is performed from the underside of the joint.

Partial Joint Penetration: Joint penetration which is less than complete.

Plug Weld: A circular weld made through a hole in one member of a lap or a tee joint joining that member to the other.

Semi-automatic Arc Welding: Arc welding with equipment which controls only the filler metal feed. The advance of the welding is manually controlled.

Shielded Metal Arc Welding (SMAW): An arc welding process wherein coalescence is produced by heating with an arc between a covered metal electrode and the work. Shielding is obtained form decomposition of the electrode covering. Pressure is not used and the filler metal is obtained form the electrode.

Slag Inclusion: Non-metallic solid material entrapped in weld metal or between weld metal and base metal.

Submerged Arc Welding (SAW): An arc welding process wherein coalescence is produced by heating with an arc or arcs between a bare metal electrode or electrodes and the work. The arc is shielded by a blanket of granular, fusible material on the work. Pressure is not used and filler metal is obtained from the electrode and sometimes from a supplementary welding rod.

Tee Joint: A joint between two members located approximately at right angles to each other in the form of a T.

Vertical Welding: The position of welding wherein the axis of the weld is approximately vertical.

Weld Metal: That portion of a weld which has been melted during welding.

Weldability: The capacity of a metal to be welded under the fabrication conditions imposed into a specific, suitably designed structure and to perform satisfactorily in the intended service.

Weldment: An assembly whose components parts are joined by welding.

VITA

John Paul Christein was born in Warren, Ohio on June 12, 1956. He graduated from public schools and in December 1979 earned his Bachelor of Engineering Degree in Civil Engineering at Youngstown State University in Youngstown, Ohio.

In January 1980, Mr. Christein began his career in hull engineering at Newport News Shipbuilding and Dry Dock Company in Newport News, Virginia. Initially, his work involved various structural engineering activities to support the design and construction of Nimitz-class aircraft carriers.

Presently, Mr. Christein is a senior engineer in the hull technical group of the new construction non-nuclear aircraft carrier project. He is responsible for providing welding expertise for the project. Other responsiblities include designing of ship structure and technically supporting the construction of aircraft carriers CVN 72 Abraham Lincoln, CVN 73 George Washington, CVN 74 John C. Stennis, and CVN 75 United States which are now in various stages of construction.

Mr. Christein began his graduate studies at Virginia Polytechnic Institute and State University in December 1987. He is a licensed professional engineer in the state of Virginia and is a member of the United States Naval Institute.

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