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Weld Design of Heavy Duty Vehicle Bodies

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A thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements of the Degree of Masters of Science in Mechanical Engineering (Applied Mechanics Stream)

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Candidate's Declaration

I hereby declare that the work which is being presented in this thesis entitled 'Weld Design of Heavy Duty Vehicle Bodies' is original work of my own has not been presented for a degree in any other University and that all sources of material used for the thesis have been duly acknowledged.

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November 2007
Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

Dr.Ing. Tamrat Tesfaye
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November 2007
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PREFACE

Chapter one of the thesis deals with the objective of the paper and review of literature on the subject matter of weld design and processes. In this part different authors' views on the weld design, weld process, weld test and inspection are gone through briefly.

Chapter two lays the basis for the fundamental concepts of weld design; in this part the detail of engineering background of weld design is treated. In chapter three, the common weld processes and their selection criteria are dealt with. In chapter four, the idea of weld test and inspection is briefly presented.

The analysis of weld design and process on selected fabrications of local heavy-duty vehicle body builders is presented in chapter five; this part is the target of the paper in which the problems related to weld of local body builders is identified.

Finally, conclusion is drawn in chapter six. In this chapter, recommendations for the problems are given and eventually, future works are indicated.

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ABSTRACT

The welding process has been used extensively in the fabrication of many structures including ships, airplanes, buildings, bridges, vehicle bodies, pressure vessels, etc. It provides many advantages over other joining techniques. To mention only a few, it provides better mechanical properties, air and water tightness and good joining efficiency.

However, there are various problems such as residual stresses and shape distortion associated with the construction of welded structures. When a material is being welded, it experiences local heat due to the welding heat source. The temperature field inside the weldment is not uniform and changes as the welding progresses. The welding heat cycle gives rise to a complex strain field in the weld metal and in the base metal regions near the weld. These strains, along with the plastic upsetting, create the residual stresses that remain after the welding is completed. In addition, shrinkage and distortion are also produced. Residual stresses and distortion are highly undesirable in welding technology. Thermal stresses during welding often cause cracking.

Some of the above weld related problems can be solved by adhering to a preset weld design practice and employing appropriate weld process procedure in the welding tasks.

In our country, Ethiopia, there are limited numbers of heavy duty vehicles body builders. Those body builders extensively use welding. In those local body builders there is lack of proper weld design practice in the fabrication of heavy duty vehicle bodies. Moreover, there is no well developed/structured welding process procedure they have adapted except in the cases of internationally undertaken projects.

This fact enhances the weld related problem mentioned above on the vehicle bodies fabricated locally. In this paper case study is made on four local representative vehicle body builders focusing on their weld design and

processes. From the case studies the general problems related to the weld design and process of the local heavy duty vehicle body builders is identified. Eventually, general recommendation is made on weld design and process of heavy duty vehicle bodies that the Ethiopian heavy duty vehicle body builders are to adapt or practice.

CHAPTER ONE

1. INTRODUCTION

1.1 OBJECTIVES

One of the objectives of a postgraduate thesis is to add knowledge to the field of a study and to solve problem of a specific industry. In line with the underlining objective of post graduate thesis, this thesis 'Weld Design of Heavy Duty Vehicle Bodies' can be categorized under the objective focusing on solving problem of a specific industry.

The objective of this thesis is to propose solution for problems observed in the weld design and process of heavy-duty vehicle body building industry. Specifically, the weld design and process related problems of selected local heavy-duty vehicle body builders are identified and then engineering solutions proposed.

The paper will indicate the local heavy-duty body builders the inherent problems in their weld design and process of fabrication. It will not only indicate the problems but also recommend solutions to the problems and by doing so improve their product quality.

The objective of this thesis can be summarized by two points explained as follows:

- Identify the problems related to weld design and process of local selected heavy duty vehicle body builders;
- Propose engineering solution which enables them to solve their problems

1.2 STATEMENT OF THE PROBLEM

Heavy duty vehicle bodies which are fabricated in our local body builders mainly employ welding technology. However, the design and process selection aspect of the technology is not to the level of standard engineering requirement. This fact has detrimental effect on quality, reliability and service life of the products. Hence the paper addresses this problem.

1.3 DEFINITION

A weld can be defined broadly as a localized union accomplished by applying heat and/or pressure with or without extra material being added. [5]

When the thing to be made is large, or when only a few copies are needed, it is usually more practical to join simple pieces by welding, bolting, or riveting than to create a single entity by casting or machining. Such welded assemblies are called weldments. Today's automobile body is a weldment, a single unit combining the functions of body and frame. Steel ships are also weldments. In both cases, the superior properties and economy of sheet metal are realized by using welding to produce a complex article. Welding has also become more economical for high-volume production with the use of robots, which can be programmed to produce a complex series of perfect welds.

1.4 ORGANIZATION OF THE THESIS

In order to materialize this thesis a couple of approaches are integrated which are supportive (supplementary) to each other. In the first approach, literature is reviewed on the subject matter of the thesis 'Weld Design of Heavy Duty Vehicle Bodies'. From this review the underlying engineering concepts or ideas governing the weld design and process are extracted. The review is focusing on the possible range of weld designs and processes employed at heavy-duty vehicle body building industry.

The review includes weld design, weld process, weld process selection, low carbon steel welding and its effect, welding test and inspection.

The second approach is the analysis of weld design and process of selected heavy-duty vehicle bodies fabricated by representative local body builders. In this approach the detail of the weld design and processes the body builders employ on their specific product lines is analyzed. This is one of the important parts of the thesis which enable to identify the problems involved in the weld design and process of local heavy-duty vehicle body builders.

The problems are categorized systematically and their possible sources are identified. The identified problems are substantiated with the governing principles of weld design and process to propose solution.

1.5 LITERATURE REVIEW

A number of authors have written on weld designs and processes. For the weld design the authors materials reviewed are Davis, Arthur Cyril, **The Science and Practice of Welding**, England University Press, Cambridge, 1977[1]; Morris, Joe Lawrence, **Welding Processes and Procedures**, Prentice Hall, New York, 1962 [6]; Kenneth S. Edwards, **Fundamentals of Mechanical Component Design**, McGraw-Hill, Inc. NY, 1991[5]; Harold A. Roth Bart, **Mechanical Design and Systems Handbook**, McGraw-Hill, Singapore, 1985 [2]; and Joseph E. Shigley, **Standard Handbook of Machine Design**, McGraw-Hill,1996 [4]. in these materials the detail of weld designs are well addressed. Concerning the weld design the base for this paper is the weld design concept extracted from these authors material.

In similar manner for weld process the authors material reviewed are, Houldcroft, Peter Thomas, **Welding Process Technology**, Cambridge University Press, Cambridge, 1977 [3]; Smith, Dave, **Welding Skills and technology**, Gregg Division, New York, 1984 [8]; and Nikolaev, Georgii Aleksandrovich, **Advanced welding process**, Mir Publishers, Moscow, 1977 [7]. In these authors materials the details of welding processes are presented.

Finally, for weld test, inspection, codes, standard and specifications the authors material reviewed are, Davis, Arthur Cyril, **The Science and Practice of welding**, England University Press, Cambridge, 1977 [1]; Smith, Dave, **Welding Skills and technology**, Gregg Division, New York, 1984 [8]; Harold A. Roth Bart, **Mechanical Design and Systems Handbook**, McGraw-Hill, Singapore, 1985 [2]; Kenneth S. Edwards, **Fundamentals of Mechanical Component Design**, McGraw-Hill, Inc. NY,1991 [8]; Joseph E. Shigley, **Standard Handbook of Machine Design**, McGraw-Hill,1996 [4].

CHAPTER TWO

2. WELD DESIGN

2.1. GENERAL WELD DESIGN CONSIDERATIONS

In weld design, the following factors [9] should be taken into consideration:

1. Purposes and conditions of use, economic factors, service period.
2. Stress analysis
3. Determination of shape and size of weld joints
4. Selection of material
5. Determination of weld procedures
6. Determination of treatment and inspection procedures after welding

The following general rules [2] apply:

- 1) Metals being joined must have approximately the same melting point
- 2) Welded joints have the same strength as the annealed material of the parts welded, if the welding metal is of the same analysis as the base metal. When tensile tested to failure, the joint will usually break at the edge of the weld in the base-metal area annealed by the welding heat rather than at the weld. Welded fittings may be heat-treated after welding to remove cooling strains and overheated spots in the fitting. Welded alloy steels should be heat-treated after welding if possible.
- 3) Materials of equal thicknesses are best suited for welding. Where the thickness ratio is 1:1.5 or less, the materials are considered to be of equal heating value and can be welded easily.
- 4) Joints prepared for welding should have the edges beveled on one or both pieces to allow space for filling in the welding material, which should be of nearly the same analysis as the welded pieces.
- 5) Single-plate gussets, welded on one side only, should have the weld carried around the end to provide positive anchoring of the gusset end.
- 6) Welded joints should not be designed to take bending loads unless supported by auxiliary means such as pinning, riveting, telescoping, or other positive support.

- 7) Avoid joints between thin and thick sections. Materials where the thickness ratio is greater than 1:1.5 are considered to be of unequal heating value and are difficult to weld. A maximum ratio of 1:3 is normally considered the limit. An exception to this exists where one side of the joint has a greater thickness but smaller mass. For instance, a 3 mm thick continuous sheet can be welded to a 25 mm³ because the block, once heated, will not dissipate the heat as rapidly as the continuous sheet containing the greater area.
- 8) Avoid the convergence of more than six members to form a welded cluster. The repeated application of heat on the small area where all members meet weakened the base metal adjacent to the re-melted weld metal.
- 9) Do not use tin-lead solder in the proximity of a joint. Repair of the joint might cause contamination of the weld metal with subsequent embrittlement and cracking of the affected area.
- 10) Do not weld a brazed joint. The reverse practice of brazing a welded joint is permissible.
- 11) Avoid a joint which requires welding at the inside junction of two members forming an acute angle.
- 12) Avoid joints in parts which are heat-treated before welding, especially to a tensile strength in excess of 860 MPa.
- 13) Avoid washers welded to lugs or other parts of fittings.
- 14) Do not use parts previously spot-welded because of the probability of inclusion of flux or flux-removal fluid in the spot welded seam.
- 15) Avoid designs which require welding into deep pockets, which are difficult to handle because of blow back or arc-over them maximum condition should be a corner where three plates intersect at right angles to one another. The corner should be left open if possible.
- 16) Avoid welding parts having widely different melting points.

2.2 DETAIL WELDING DESIGN CONSIDERATION

Three factors influence the length of fusion welds, namely, strength requirements, design of the parts, and distortion of the parts and possible resultant cracking of the weld. Depending upon these factors, welds may be either continuous, intermittent, or tack welds.

Continuous welds are used whenever strength requirements are high, or where a liquid or gastight joint is required. They are costly because of the post welding straightening operation usually required to eliminate distortion caused by the heat of the welding operation. Intermittent welds are used on long joints where strength and rigidity requirements are not exacting enough to warrant the extra cost and weight of a continuous weld.

There are five fundamental types of welded joints, namely butt, lap, corner, edge or flange and tee. The more common types of welding applied to these joints are given in Appendix-V. Recommendations on structural efficiency are given in Appendix-VI.

In all types of butt welds, the strength characteristics may be improved by welding both sides. However, welding both sides is not recommended on steel or aluminum alloys **in gages less than 0.125, or on any gage of magnesium alloy.**

Fittings should be made simply, with the smallest practicable number of component parts to reduce welding to a minimum. Single-piece forgings or castings are preferable to built up welded fittings.

When welding sheets or tube to fittings, the thinner stock is frequently burned away before the thicker material is brought to the fusing point. Furthermore, finish machining of a heavy fittings included in a welded assembly can not be completed because excessive warpage or shrinkage has left insufficient material for the final operation. It is therefore necessary to rough machine all heavy fittings prior to gas welding to eliminate excess material, reducing the area to be welded to a thickness not to exceed three times the thickness of the attaching

members. When such precautions are exercised, it may be machined to within ± 0.75 mm of its final thickness before welding.

A bead around a welded fitting helps eliminate warpage and cracking by permitting expansion and contraction. If the members to be joined are of the same diameter, they should be welded at a 30° angle scarf joint. A tubular liner should be used, extending at least 25 mm and \varnothing 32 mm whichever is greater, beyond the welded joint. This not only prevents reduction of diameter when the joint is under tension but also serves to align the tube ends for welding. All liners must fit snugly inside the tubular members.

Tubes of different diameters should be telescoped one inside the other. The tubing may be swaged or a sleeve may be used to ensure a snug fit. The female tube (and sleeve, if used) must be scarfed or fishmouthed.

Truss joints generally involve one continuous member, to which are welded vertical and/or diagonal members. The axes of several members must intersect at a common point to avoid eccentric loading. The fixity and tensile strength of such joints are increased by the use of gussets. They also permit gradual introduction of the stress into the joint.

Because of stress concentration, welds in slotted tubes should not end diametrically opposite one another. A minimum diagonal of 30° across the tube should be maintained. Single plate gussets 1.5 mm thick and under should be welded on one side only and have the weld carried around the end to provide positive anchoring of the gusset plate. Gussets over 1.5 mm thick should be welded on both sides.

Slicing of tubes can often be done conveniently near a truss joint, which tends to strengthen the slice.

Lugs may be welded to any point on a member if the load of the lug is of low magnitude. High stress lugs should be located at truss points. Washers or

bushings may be welded to lugs to increase bearing area when weight is critical, but this practice must not be followed on highly stressed fittings.

End fittings designed for tubular members may be forgings flash welded to the tubes where large quantities are involved.

For highly stressed members of limited quantity the fitting may be a forging or high-tensile steel casting joined to the tube by a fishmouth weld or similar method. Abrupt changes in section must be avoided because of the probability of high stress concentrations.

Plug or slot welds may be employed for attaching two sheets or plates at specific points. A certain degree of local warping usually accompanies this process. Plug welds are often used in lieu of spot welds to assemble plate stock too thick to be spot-welded with available machines. [2]

2.3 INFLUENCING FACTORS IN WELDING

The major undesirable factors to be considered in selecting welding as opposed to other joining methods are:

- 1) The possibility of generating inferior welds
- 2) Incomplete knowledge of the fatigue characteristics of welded joints
- 3) Undesirable mechanical properties in the weld & heat affected zones
- 4) Thermal stresses

A non-destructive test is often specified to evaluate the physical soundness of the weld. As explained in chapter four of this paper such methods include, x-ray, magnetic flux, and ultrasonic test. Exact standards must be specified for each joint and should be based upon tests on the actual part.

Fatigue failures show after some time has passed and may not be recognized as a limiting factor until many units are in service. Parameters for welded joints which will experience fatigue are given by the AWS & AISC code, see

appendices-X. These codes were developed for structures but are adaptable to machines and equipment which also experience fatigue.

A general rule for the design of weldments for fatigue resistance is similar to that for any fatigue-prone-part abrupt section changes should be avoided. For this reason, simple butt welds are better in fatigue than lap and fillet joints, butt welds without reinforcement because section change is absent. Transverse attachments also lower fatigue resistance.

Design for welded joints which will experience fatigue should avoid excessive reinforcements, under cuts, lack of penetration, and rough welds. Other design considerations include the following:

- 1) Welded joints should not be made in a region which will experience flexure,
- 2) Fatigue resistance is generally higher in the rolling direction of sheet of metal, and
- 3) Eccentric loads, biaxial and tri-axial stresses, and restrained internal sections should be avoided.

The fatigue strength is a function of both the type of joint and the loading. Low working stresses are necessary because the weld joint results in stress concentration.

Accepted values of the stress concentration factor K are as follows butt weld machined, 1.2; fillet weld at toe, 1.5; fillet weld at end, 2.7; and tee butt joint, sharp corners, 2.0. More desirable values of the stress concentration factor can be obtained with improved work quality. The data in Appendices-VII together with the information mentioned above show that the smooth butt welds should be used wherever possible.

The subject of corrosion and its relation to welded metals is complex. The combination of base metal and weld metal of a different composition in the presence of an electrolyte can lead to corrosion. Also, localized corrosion can

occur & if the metal anode surface or volume is small in comparison with that of the cathode.[2]

2.4 STRENGTH OF WELD JOINT

In designing a structure which are planed to be fabricated by welding, various types of strength of the weld joint must be taken into consideration, such as tensile strength, impact strength, fatigue strength, creep-rupture strength, etc. depending on the requirements.

2.4.1 Static strength

The strength calculation is based upon the allowable stress, and the maximum safety load, defined as the load by which the stress to be raised in that structure becomes allowable stress.

Where a weld has a convex reinforcement, the stress raised around the weld is concentrated to the toes, and according to the experiments, the concentrated stress comes up to 1.3 to 1.8 times the stress at even parts of the weld in the case of butt joints, whereas in the front fillet welds it is 2 to 5 times, and further at the root of the front fillet weld, the stress concentration is raised up to 6 to 7 times those of other portions in the weld. This stress concentration affects the fatigue strength of weld.

The stresses in a weld due to applied load can be calculated with the following formulas, irrespective of a groove weld or a fillet weld. For sketches refer appendices-IX.

$$\sigma = \frac{P}{\sum a \times l}$$

$$\tau = \frac{P}{\sum a \times l}$$

where, σ :tensile or compressive stress in the throat section
 τ : shearing stress in the throat section
 P: applied load
 a: throat thickness

l : effective weld length

$\sum a \times l$: total area of the throat section

For the throat thickness the following points are to be considered:

a) Groove weld

In the case of a complete joint penetration weld, the thickness of the base metal is taken as the throat thickness; and where the thickness are different at the weld, the thinner one is taken as throat thickness, and the reinforcements are not included in the throat thickness.

On the other hand, in the case of the weld which has partial penetration, the throat thickness is defined as joint penetration or the total of joint penetration where the weld is made on both sides of the joint.

b) Fillet weld

The throat thickness in a fillet weld, the two members which make a right angle, is determined by the following formula, where S is the size of a fillet weld:

$$a = \frac{S}{\sqrt{2}} = 0.707 \times S$$

when the fillet weld has unequal sizes, its smaller size is commonly taken for the calculation by the formula given above. And where the two members do not make a right angle, the following formula is taken to determine the throat thickness, where θ is the angle in which the two members make a tee joint:

$$a = S \cos \frac{\theta}{2}$$

However, θ should be limited to $60^\circ \leq \theta \leq 120^\circ$. As stated above, the strength of a fillet weld is determined basically by the throat thickness calculated with the size of a fillet weld; however, the size is substituted by the leg length of a fillet weld in the drawings. Since the leg length is roughly equal to the size of fillet in general, approximately 0.7 times the leg length will be the throat thickness practically.

2.4.2 Fatigue strength [9]

Where stresses are repeatedly applied on a material it fails at lower stress than that of static load that is fatigue fracture.

The fatigue strength of a weld joint is affected not only by material itself but also by shape of joint, condition of weld, welding discontinuities, residual stress, stress concentration, type of stress and so on.

When the fatigue strength is indispensable factor on a weldment, the convexity of the weld must be limited, and in some cases, the weld reinforcement may be required to be removed to a smooth finish; and in the case of fillet weld, the concave weld may become preferable to lessen the fatigue.

2.5 WELDING JOINT DESIGN

Joining by welding affords opportunities for designers to simplify structures, save weight, reduce cost, and improve appearances. This section will discuss the various designs of joints which may be used to sustain given types of loads, the configuration of stress patterns within the joints, and other pertinent design aspects. [4]

Joints included in this section are those primarily intended for manual arc and oxy-gas welding. Three fundamental types of joints are used in conjunction with the processes. They are:

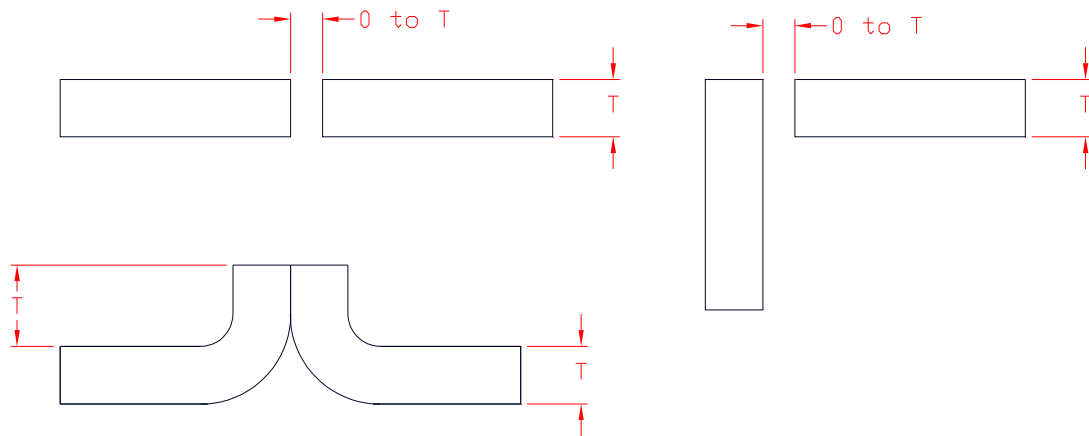
1. Groove-welded joints
2. Fillet welded
3. Combination of groove and fillet welded joints

The selection of the groove type joint will usually depend on the cost of making the joint, the mechanical properties desired, and the position in which the joint is to be welded. Only casual examinations are needed to establish the fact that butt joints consisting of square-sheared edges are more economical from the standpoint of cost than beveled edges. From the standpoint of mechanical properties, the V or U joints will be superior to the square-edges, plain butt joint because of improved weld penetration. J and U joints are better than V joints

where stress and distortion may be the governing factors, although the cost of preparation is greater. For a horizontal joint in plates contained in a vertical plane, a somewhat greater convenience is in a single bevel joint with the square edge on the bottom.

Fillet-welded joints are frequently favored by designers in the interest of lower fabrication cost if the load conditions permit. Groove welds usually require less welding but the edge preparation and fitting cost may be greater. In joints not required to be fluid-tight, and where calculations prescribe a very small size of continuous weld, a better practice may be to use intermittent welds of larger size. Fillet welds are sometimes added to groove welds to increase the efficiency of the joints and to improve stress distribution.

Square-groove joints (fig. 2-1) welded from one side are applicable only to thin materials. The mechanical properties of these joints depend chiefly upon the amount of penetration obtained.



$$T = \frac{1}{16} \text{ Max. for all joint}$$

Fig. 2-1. Square groove joints for welding one side.

Although the production of square-groove joints of this type offers the greatest economy, they should not be used in structural situations where tension due to bending is located at the root of the weld or where the joint must sustain shock or fatigue loads. Square-groove joints welded from both sides, as shown in Fig. 2-2,

depend in strength upon the extent of penetration obtained and the throat dimensions of the fillet if the latter is used. For joints with incomplete penetration, strict control must be imposed if uniformity of results is expected. Complete penetration can be obtained on materials of 3 mm.

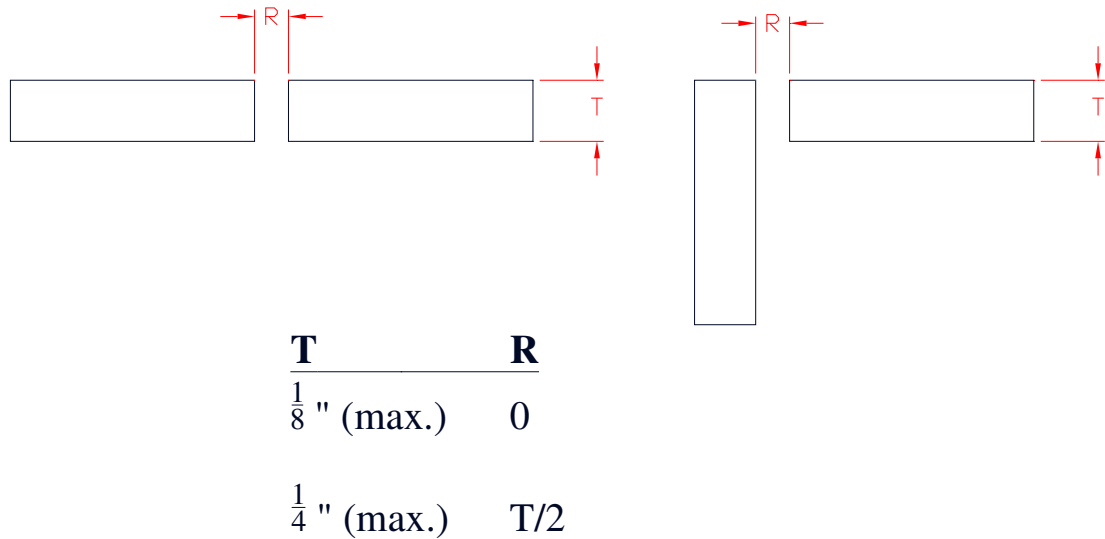
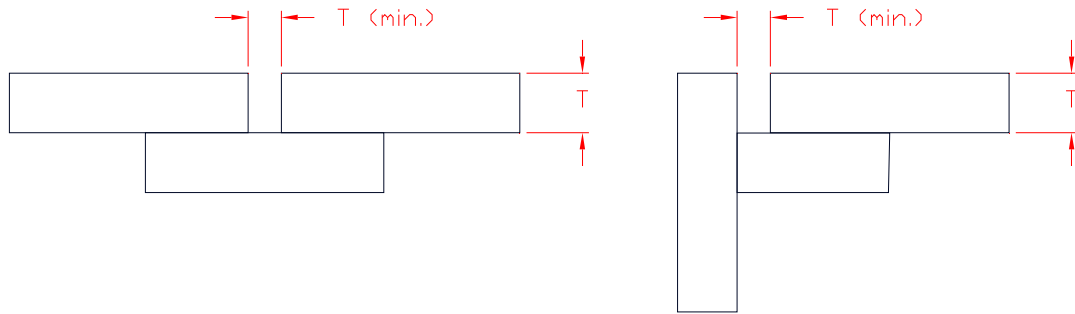


Fig. 2-2. Square groove joints for welding both sides.

and under, with no root opening, and on materials up to 6 mm in thickness, with root opening equal to one-half the thickness. In materials 5 mm and 6 mm thick, the first weld should be back-chipped to sound metal before depositing the second weld.

Joints with incomplete penetration may be used for any type of load; joints with incomplete fusion should be used only for static loading. These joints offer good economy in welding. Square-groove joints welded on one side (Fig. 2-3), with backing and complete penetration, are suitable for all types of loading. The root opening should equal the thickness of the materials. They are not recommended for thicknesses greater than 5 mm. This joint is economical both to prepare and weld.



$$T = \frac{3}{16} \text{ " (max.)}$$

Fig. 2-3. Square groove joints for welding one side with backing

Single V groove joints welded from one side with complete penetration, incomplete penetration, and complete penetration with backing, as shown in Fig. 2-4, offer good welding economy in thicknesses of less than 20 mm. These joints without backing are not desirable if the load imposes bending against the root side. Joints welded on one side with complete or incomplete penetration should not be used for shock or impact loading.

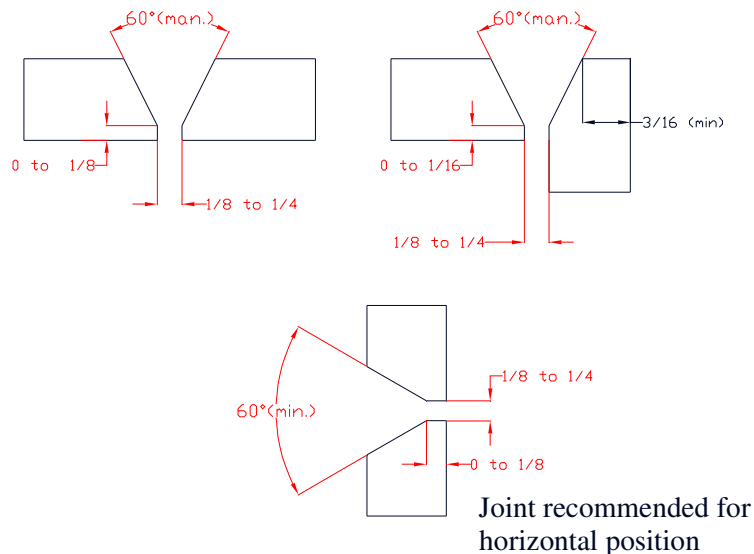


Fig. 2-4.a. Square-V groove joints for welding one or both sides.

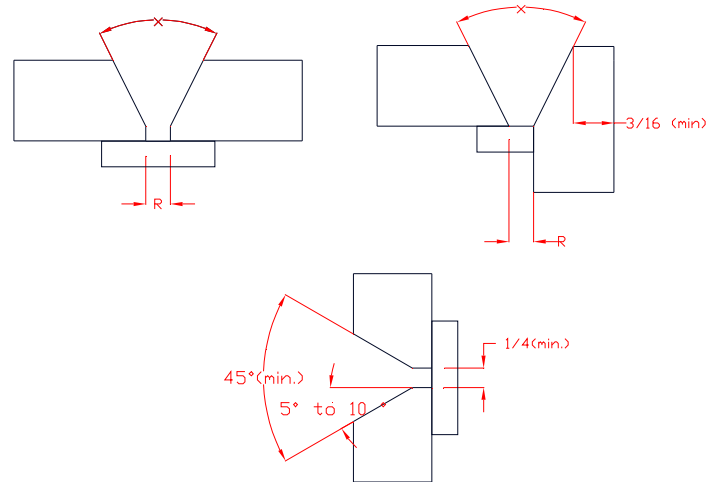


Fig. 2-4.b Square-V groove joints for welding one with backing.

Single V groove joints welded from both sides with complete penetration are suitable for all types of loads and have full strength. The welding economy is good for thicknesses up to 20 mm. Back-chipping to sound metal should be done before placing the back weld.

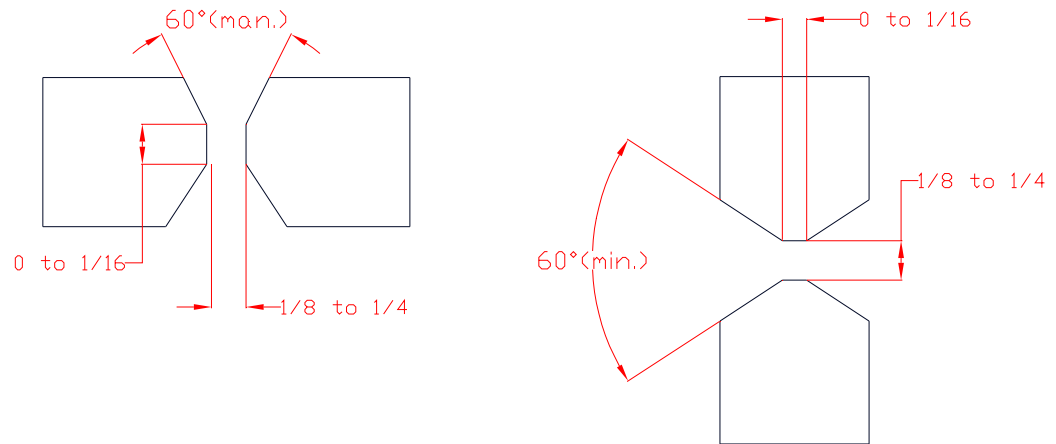


Fig. 2-5 Double-V groove joints for welding both sides.

In this joint, if it is of the corner type, a fillet may be applied to obtain additional strength.

Double-V groove joints (Fig. 2-5) welded with complete and incomplete penetration, produce strengths varying with the extent

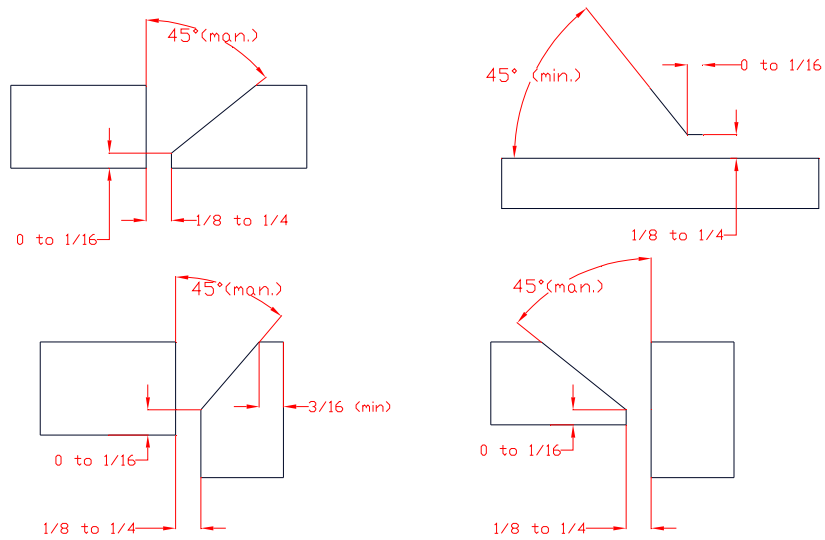


Fig. 2-6a. Single-bevel groove joints for welding one or both sides.

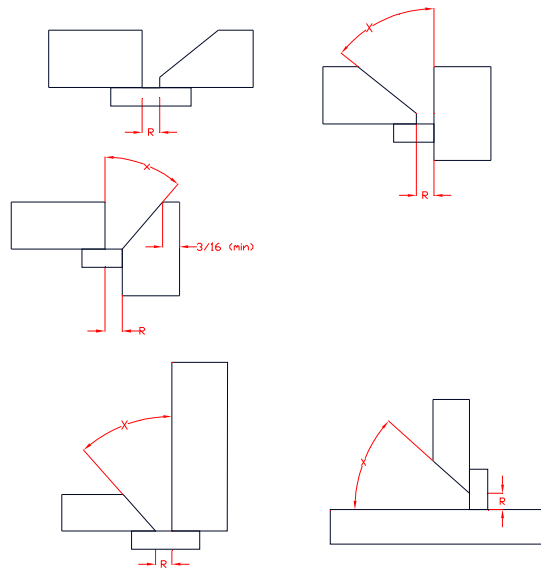


Fig. 2-6b. Single-bevel groove joints for welding one with backing.

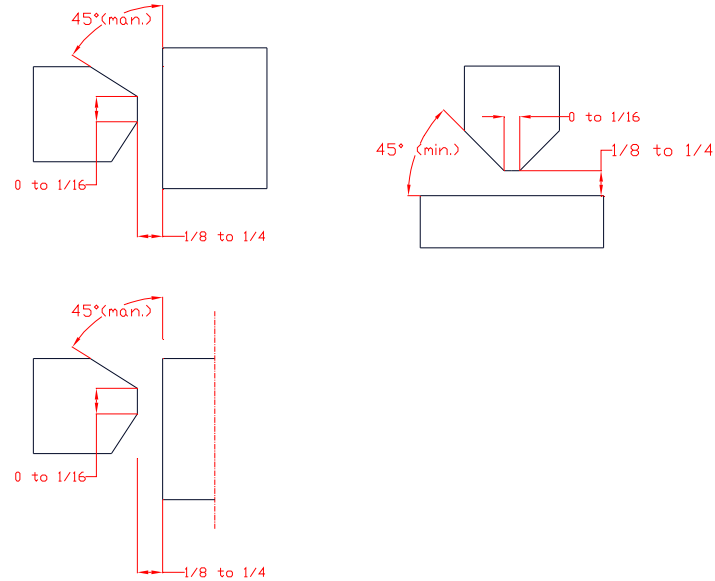


Fig. 2-7 Double-bevel groove joints for welding both sides.

of the penetration. Incompletely penetrated joints should not be used for other than static-type loads. From the standpoint of welding, these joints are economical if thickness do not exceed about 40 mm. To obtain full penetration, backchipping to sound metal should be done before depositing the second weld. Single-bevel groove joints, welded from one side with incomplete and complete penetration, with backing (Fig. 2-6), offer good welding economy where the depth of the chamfering does not exceed 20 mm. The perpendicular groove face may present some difficulty in producing a sound weld. Joints with incomplete penetration and unbacked root should not be used where the load sustained causes bending stresses to concentrate at the weld root.

Single bevel groove joints welded from both sides with complete penetration are suitable for all types of loads. To obtain full strength, back-chipping of the first weld before depositing the second is recommended. Corner and T joints may be given additional strength by use of fillet welds.

Double-bevel groove joints with complete and incomplete penetration (Fig. 2-7) exhibit good welding economy if the plate thickness does not exceed about 40 mm. Only those joints having complete penetration should be used for impact or shock loading. Some difficulty is evidenced by the presence of a perpendicular

groove wall. Full strength is obtained by back-chipping the first weld before depositing the second in the case of fully penetrated joints.

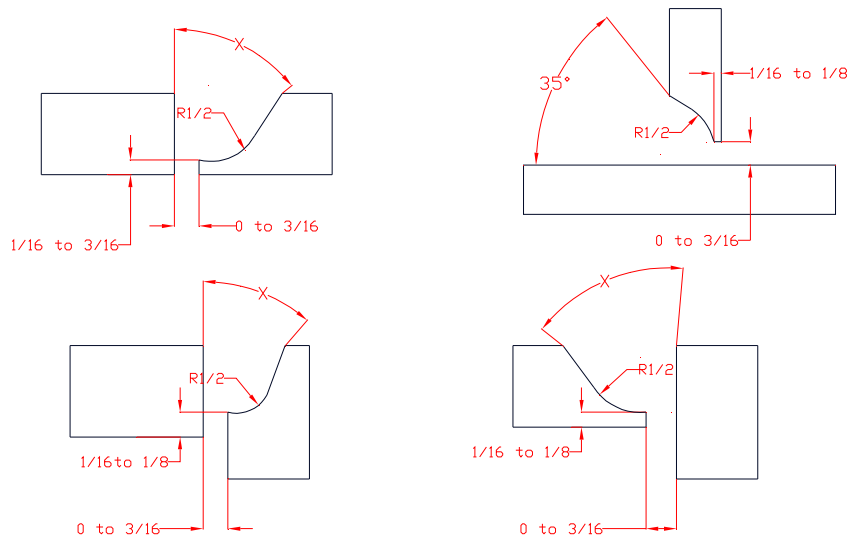
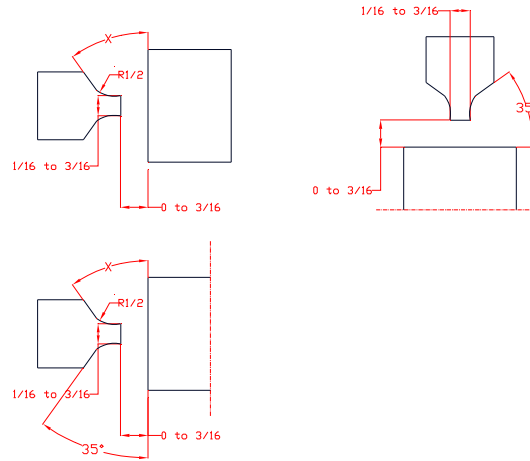


Fig.2-8. Single-J groove joints for welding one or both sides.

Single J groove joints welded from one side with complete and incomplete penetration (Fig. 2-8) show improved welding economy when depth of chamfering exceeds 20 mm. Neither of these joints should be used when tensile loads are concentrated at the root of the weld, nor should they be used for shock- and impact-load transmission. Sound welds may be obtained with difficulty due to the perpendicular groove walls.



Angle X	Positio
35° (min.)	All
25°(min.)	F, V, O

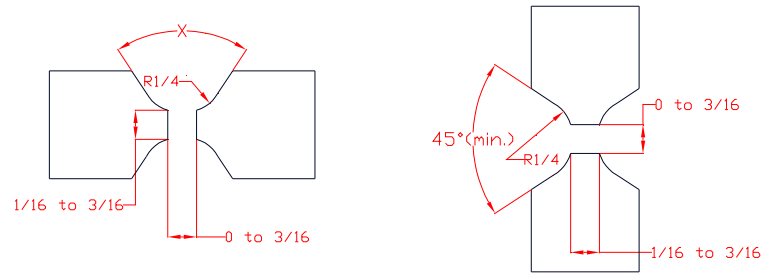
Fig. 2-9. Double-J groove joints for welding both sides.

The J edge is more expensive to prepare than the bevel.

Single-J groove joints welded from both sides with complete penetration will sustain all types of loads with full strength. In T and corner joints, a fillet weld may be used for additional strength.

This joint is more expensive to prepare than the single bevel but affords greater welding economy when thicknesses exceed 20 mm.

The mechanical properties of double-J groove joints (Fig. 2-9), welded from both sides with complete penetration, will depend upon the degree of penetration obtained. Joints incompletely penetrated should not be used for shock and impact loads. In joints completely penetrated, if full strength is required, the first weld should be back-chipped to sound metal before depositing the second. T and corner joints may be given additional strength by use of fillet welds. The double J groove joints offer better welding economy than the double bevel groove joint if the extent of chamfering exceeds 20 mm. but are more expensive to prepare.



Angle X	Positions	
45° (min.)	All	Joint recommended for horizontal position
20° (min.)	F, V, O	

Fig. 2-11. Double-U groove joints for welding both sides.

Single U groove joints (Fig. 2-10) welded from one side with complete and incomplete penetration offer good welding economy when chamfering exceeds 20 mm. The strength of these joints depends upon the extent of joint penetration obtained; incompletely penetrated joints should not be used for shock or impact loading. Neither of these joints should be used where tensile loads are concentrated at the weld root. This type of groove is easier to weld, but more expensive to prepare, than the V.

Single U groove joints welded from both sides with complete penetration produce full strength and are suitable for all types of loads. To obtain full strength, it is recommended that the first weld be back-chipped before depositing the second. These joints have good welding economy and are easier to weld, but more expensive to prepare, than some other types. The corner joints may have a fillet added for greater strength.

Double U groove joints welded from both sides with complete and incomplete penetration (Fig. 2-11) produce strengths which depend primarily upon the amount of penetration obtained. Only the joints having complete penetration should be used for fatigue

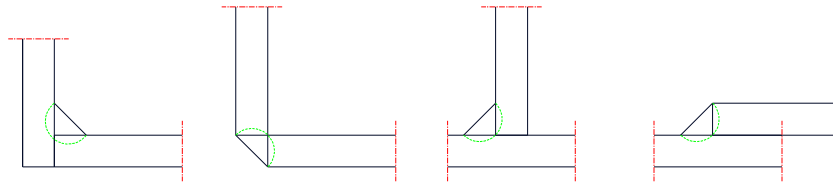


Fig. 2-12a. Single-fillet welded joints . (a)

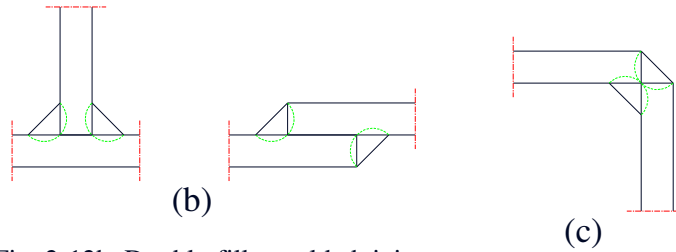


Fig. 2-12b. Double-fillet welded joints.
c. Double-fillet welded corner joint

and impact loading. To produce full strength, the first weld should be backchipped before depositing the second. These joints are easy to weld and offer good welding economy in the thicker materials but are more expensive to prepare.

Single fillet-welded joints (Fig. 2-12) require no special preparation, have good welding economy in the smaller sizes, and are easy to weld. These joints should not be used for fatigue and impact loading or where tension due to bending is concentrated at the weld root.

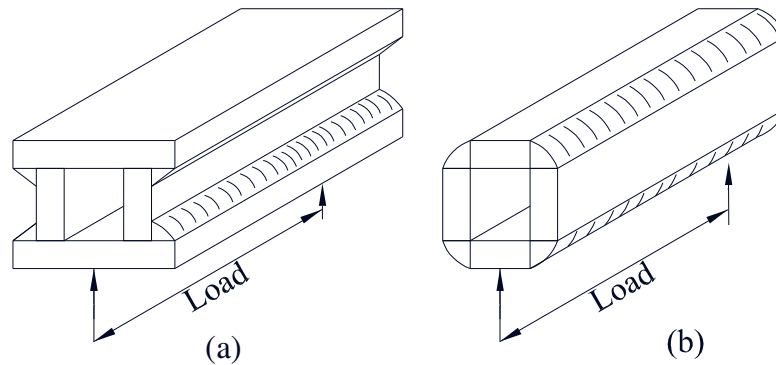


Fig. 2-13. Box beam fabricated in two ways. a. The fillet welds are only in longitudinal shear, of low values. b. The welds sustain both longitudinal and transverse shear. Method (a) is preferred

The strength of this joint depends upon the size of fillet (where size is defined as the leg dimensions of a 45° right triangle representing the fillet cross-section).

Double fillet welded joints require no special preparation, are easy to weld, and offer good welding economy in moderate sizes.

Full strength can be obtained by using adequate sizes of fillet welds. Maximum strength in the lap joints is obtained when the lap is $5T$ (T = thickness of thinner member).

Double fillet-welded corner joints (Fig. 2-12) with complete joint penetration are capable of producing full strength for all type of loading; however, to obtain full strength it is recommended that the first weld be back-chipped to sound metal before depositing the second weld. This joint offer good welding economy in moderate thicknesses. [6]

2.5.1 Location of joints within a member

It is usually possible to arrange joining members so that welds may not have to take the entire transmitted load.

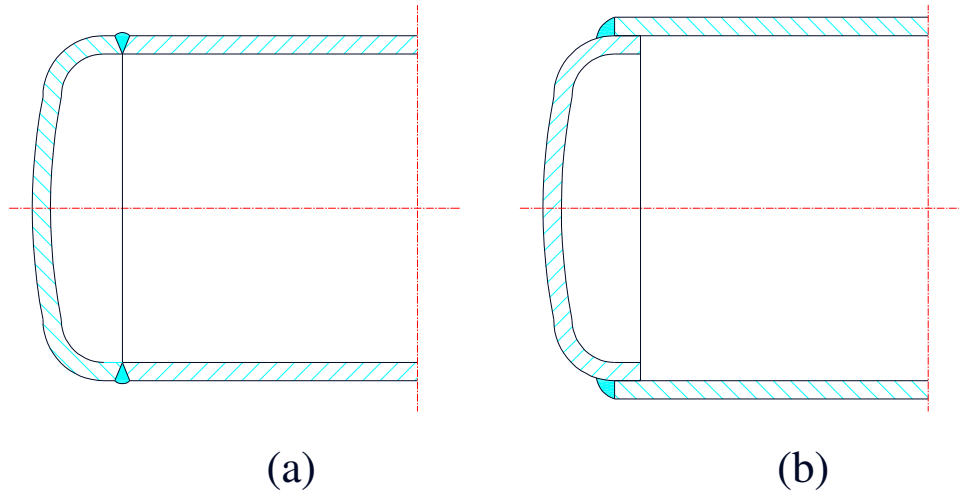


Fig. 2-14 Convex tank heads. a. Weld in tension. b. Weld in shear

The box section shown in Fig. 2-13 is designed in two ways. In **a**, if the section acts as a beam, it is readily seen that the welds are primarily in longitudinal shear of low unit value while in **b** all transmitted loads are carried by the welds. In **a**, the several parts comprising the section could substantially serve its purpose without the welds, but this could not possibly be true in **b**. Since the shear strength of a metal is lower than its tensile strength, the designer should be alert to the possibilities of joining members in tension rather than in shear. This factor alone leads to designs which are appreciably lighter and more serviceable. Figure 2-14 illustrates this principle in the simple example of tank heads. The weld is in tension in **a** while in **b** the weld is of the fillet-type and carries its load in shear. It is well to note that, of the two, the butt-joint construction has a more pleasing streamlined appearance.

Special attention should be directed toward locating welds most advantageously if the filler material has lower yield strength than the parent metal. Should plastic flow occur in a weld while the parent metal remains elastic, early failure in the weld is inevitable.

To safeguard against failures of this nature, it is of the utmost importance that the weld beads be located, where possible, to serve as a keying effect rather than to

carry the direct stress. Where shear load is encountered, the longitudinal direction should be used if possible.

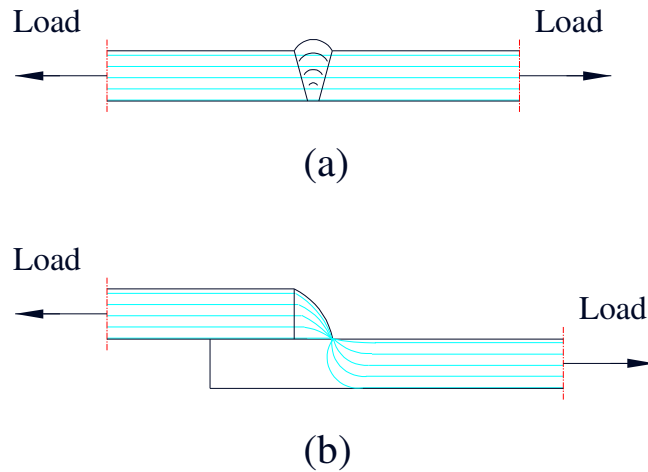


Fig. 2-15 Stress as transmitted by (a) butt joint and (b) lap joint. Note stress concentration at change of shape in lap joint.

2.5.2 Transmission of stresses through joints

Modern methods of stress analysis show that a particular contour in the bead finish has significant influence on the ultimate service life of the member and the manner in which it may fail. Lines of stress are comparable to taut rubber bands confined by the physical outline of the joint, hence any sharp change in the shape of the joint member will cause a concentration of the stress lines at that point. Although the stress calculations may be entirely within safe limits when based on uniform distribution, this condition is rarely realized in service. This design feature is of growing importance because of speed and stress increases in machinery.

Butt joints give the most satisfactory distribution of stresses of all the joints used for welding. The comparison between the distribution of stress in a butt joint and a lap joint is shown in Fig. 2-15. [6]

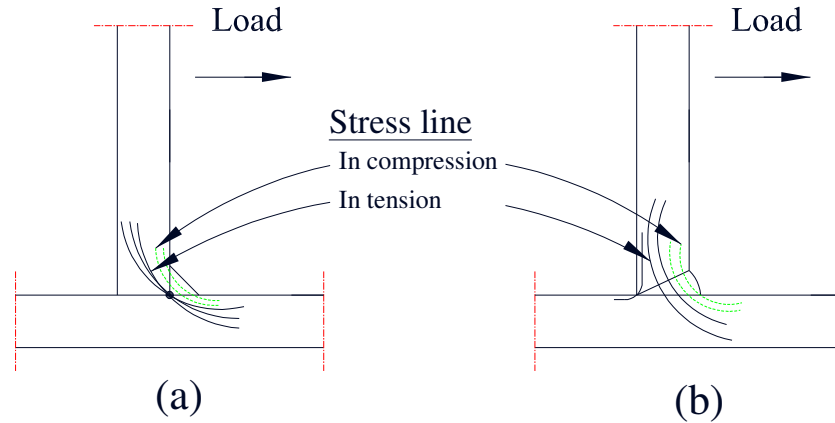


Fig. 2-16. T-joint fillet-welded, showing stress concentration at unfused root. T joint welded with 100% penetration, showing more favorable distribution of stress.

It is important to point out that in the finishing of joints no undercut alongside the weld deposit is permissible. Excessive reinforcement tends to give poor stress distribution. In average field procedure, about 10% buildup or reinforcement is recommended to assure a full section in butt joints. The ideal practice would be to chip and grind the weld flush with the plate surface to finish, although the expense incurred is usually not justifiable.

In welding design T joints are used for attaching surfaces normal to each other. This type of joint is comparatively low in endurance strength, a condition emanating from poor stress distribution within the joint, there being a rather sharp change in the direction of stress flow in transferring the load from one member to the other. In Fig. 2-16a it is seen that, with the existence of an un-fused root, stress concentrations will be set up, which, under some load conditions, will not be conducive to a long service life. The stress distribution in the root may be improved by use of the joint type shown in fig. 2-16b. Of equal importance is the shape of the fillet bead used to weld a T joint. Fillet welds of convex shape give a poor distribution of stress, add unnecessary weight, and, with some classes of filler material, indicate poor welding technique. Where unit stress is low and appearance thought to be improved by convex beads, their use is permissible. In

joints of members sustaining dynamic loads, the concave fillet bead is preferred by the most judicious designers, since tests, both laboratory and field, show that its life span is greater than that of the convex bead. The straight-faced bead is a compromise between the two extremes and is both reliable and economical for general construction work. [6]

2.6 DISTORTION AND HEAT FLOW

Distortion associated with a given material and welding process is a function of joint design. This phenomenon is due to the unequal cooling rate which exists between the materials being welded and the materials being used for the weld (bead). [7]

The following rules should be observed to minimize distortion:

Use U or J joints in preference to V or bevel.

Use double joints (front and back) where thickness warrants instead of single joints.

In both cases the prescribed method uses less weld metal, this reduces heat in put and therefore distortion. Distortion is also related to type of weld deposits.

Preheating before welding serves to reduce distortion by reducing thermal gradients. Metal thickness and joint type affect the flow of heat away from the weld bead and therefore affect resulting distortion. [2]

2.7 REMOVAL OF DISTORTION

In welding a structure, it is desirable that various preventive countermeasures for suppressing the occurrence of distortion are taken in advance. However, it is considerably difficult to suppress them completely.

When a structure is welded, it is caused to contract and distort, and at the same time residual stress is generated in the structure. When it is attempted to lessen the distortion by restraining it, residual stress becomes larger, and on the

contrary, when it is attempted to lessen residual stress, the distortion become larger. It is very difficult to lessen both simultaneously.

Generally, as for a weldment made of thick plate, welding residual stress rather becomes an important matter to be settled. In the case of a structure of thin plate, welding distortion rather becomes an important matter to be settled.

Since the distortion of a structure caused by welding will become one of the defects of a final product, the distorted portion must be corrected by one of the following distortion removal methods. [9]

- a. Point contraction method for thin plate.
- b. Line contraction method for formed material.
- c. Heating followed by hammering.
- d. Heating followed by pressuring and water-cooling for thick plate.
- e. Rolling
- f. Peening
- g. Cutting

2.8 EFFECTS OF HEAT ON WELD

Heat induced by welding has the same metallurgical effect on the metals involved as heat induced from a furnace used in ordinary heat treating practice; that is, heat from the welding torch may cause grain growth, may produce an annealing treatment, may toughen, etc. Although a high percentage of weldments are sent into service without heat treatment, it is possible and frequently advisable, to heat-treat to improve their physical and mechanical properties. The following paragraphs define and describe some of the more common heat treatments given welded pieces. [6]

2.8.1 WELDING OF STEEL

From stand point of welding, steel will usually fall into two types-plain carbon and alloy. The element carbon, which is present in all commercial steels, will usually affect the final weld to a greater extent than any of the other metals. Upon cooling after welding, the amount of hardening of the plain carbon steel will be a

function of the amount of carbon and the speed of cooling. Some elements will intensify or accelerate the action of carbon. **Therefore to complete a satisfactory weld, the carbon content should be somewhat lower in presence of alloys.** Hardening and brittleness incident to the welding process lead to failure by cracking. Cracking may appear as:

1. Delayed cold cracking caused by the presence of H₂
2. High-temperature liquation cracking (hot cracking)
3. Solidification cracking
4. Lamellar tearing

Hot cracks usually appear down the center of a weld, which is the last part to solidify, while cold cracks occur in the heat affected zone (HAZ). This latter may not occur until the weld is subject to stress in service, and since they are often below the metal surface they cannot be seen, so that the first indication of their presence is failure of the joint.

The factors which lead to cold cracking are:

1. The composition of steel being welded
2. The presence of hydrogen
3. The rate of cooling of the welded joint
4. The degree of restraint(stress) on the joint

(1) Composition of the steel and carbon equivalent (Ce)

The tendency to crack increases as the carbon and alloying element content increases, and since there is a great variety in the types of steel to be welded it is convenient to convert the varying amounts of alloying elements present in a given steel into terms of a simple equivalent carbon steel, thus giving an indication of the tendency to crack. This 'carbon equivalent' can be calculated from a formula such as the following:

$$Ce = C\% + \frac{Mn\%}{6} + \frac{Cr\% + Mo\% + V\%}{5} + \frac{Ni\% + Cu\%}{15}$$

(2) The presence of hydrogen in the welded zone

The presence of hydrogen in the welded zone greatly increases the tendency to crack, the amount of hydrogen present depending upon the type of electrode used and the moisture content of its coating. A rutile coating may have a high moisture coating giving up to 30 ml of hydrogen in 100 g of weld metal. The hydrogen diffuses into the HAZ, and on cooling quickly a hard martensitic zone exists with a liability of cracks occurring. Even a small amount of hydrogen present can result in cracking in severely restrained joints. Basic (hydrogen controlled) electrodes correctly dried before use result in a very low hydrogen content. Austenitic stainless steel electrodes deposit weld metal in which the hydrogen is retained and does not diffuse into the HAZ. The weld has relatively low yield strength, and when stressed, yields and reduces the restraint on the joint, so they are used, for example, to weld steels such as armor plate which may crack when welded with basic-coated mild steel electrodes. Gas-shielded processes using CO₂ or argon-CO₂ mixtures give welds of very low hydrogen content. [6]

(3) Rate of cooling of the welded zone

The rate of cooling depends upon (1) the heat energy put into the joint and (2) the combined thickness of the metal forming the joint. Arc energy is measured in kilojoules per mm length of weld and can be found from the formula

$$Arc_energy(kJ/mm) = \frac{arc_voltage \times welding_current}{welding_speed(mm/s) \times 1000}$$

The greater the heat input into the joint the slower the rate of cooling so that the use of a large diameter electrode with high current reduces the quenching effect and thus the cracking tendency. Similarly, smaller diameter electrodes with lower current reduce the heat input and give a quicker cooling rate, increasing the tendency to crack due to the formation of hardened zones. Subsequent runs made immediately afterwards are not quenched as is the first run, but if the first or subsequent runs are allowed to cool, conditions then return to those of the first run. For this reason interpass temperature is often stipulated so as to ensure that the weld is not allowed to cool too much before the next run or pass is made. The

use of large electrodes with high currents however does not necessarily give good impact properties at low temperatures.

(4) Restraint

When a joint is being welded the heat causes expansion which is followed by rapid cooling. If the joint is part of a very rigid structure the welded zone has to accommodate the stresses due to these effects and if the weld is not ductile enough cracking may occur. The degree of restraint is a variable factor and is important when estimating the tendency to crack.

Hydrogen cracking can be avoided by:

1. Using basic hydrogen-controlled electrodes, correctly dried
2. Pre-heating

2.9 LAMELLAR TEARING

In large, highly stressed structures cracks may occur in the material of the parent plate or the HAZ of a joint, the cracks usually running parallel to the plate surface. This is known as lamellar tearing, and it is the result of very severe restraint on the joint and poor ductility, due to the presence of non-metallic inclusions running parallel to the plate surface which are difficult to detect by the usual non-destructive tests. Certain types of joint such as T, cruciform and corner are more susceptible than others. Should lamellar tearing occur the joint design should be modified and tests made on the parent plate to indicate its sensitivity to tearing, whilst buttering of the surface may also help. [1]

For structural steels in general, basic-coated electrodes are used and current electrode lists of the electrode makers should be consulted for the most up-to-date information.

When welding these steels the following points should be observed:

- a) When tack welds are used to position the work, as is the general practice, they should be well fused into the weld because, due to the rapid cooling and consequent hardening of the area around the tack weld, cracks may develop.

- b) Since the chilling effect is most marked on the first run, careful watch should be kept for any cracks which may develop. Any sealing run applied to the back of the joint should preferably be made either while the joint is still hot, or with a large electrode. The least possible number of runs should be used to fill up the V to minimize distortion.
- c) When austenitic rods are used to obtain a weld free from cracks, all the runs should be made with this type of rod and ordinary steel rods not used for subsequent runs. Plates thicker than 15 mm are preferably pre-heated to 100-200 °C to avoid cracking. Cold work and interrupted welds should generally be pre-heated.
- d) The electrode or holder should not be struck momentarily or 'flashed' by design or accident on to the plate prior to welding, since the rapid cooling of the small crater produced leads to areas of intense hardness that may result in fatigue cracks developing.
- e) Hard spots in the parent plate may be softened by post-heat applied locally but this may reduce the endurance value of the joint.

2.10 WELDING JIGS

A welding jig is utilized as a convenient method for performing welding efficiently and improving the quality of a welded structure. Welding in flat position is easier to perform and a weld of good quality free from welding defects can be made efficiently and quickly.

When many welded structures of the same specifications are to be produced and a high accuracy is required for the product, proper welding jigs, or positioners suitable for the work are used. [9]

Welding jigs have the following advantages:

1. The products become uniform and the reliability of welded portions is improved.
2. Welding can be easily performed and efficiency is raised.
3. Distortion caused by welding is restrained and deformation of product is minimized by giving pre-strain and accuracy of product is improved.

CHAPTER THREE

3. WELD PROCESS

3.1. BASIC REQUIREMENTS

The ideal weld is one in which there is complete continuity between the parts joined and every part of the joint is indistinguishable from the metal in which the joint is made. Although this ideal is not achieved in practice, welds which give satisfactory service can be made in many ways. Not every welding process is equally suitable for each metal, type of joint or application, and much of the skill of the welding engineering consists in the recognition of the essential requirements which a particular weld must satisfy and the choice of the appropriate welding process. [3]

Welding process must fulfill four requirements:

- 1) A supply of energy to create union by fusion or pressure
- 2) A mechanism for removing superficial contamination from the joint faces
- 3) Avoidance of atmospheric contamination or its effects
- 4) Control of weld metallurgy.

3.2. TYPES OF WELDING PROCESS

The simplest welding process would be one in which the two parts to be joined have their surfaces prepared to contours matching with atomic precision. Such surfaces brought together, in vacuum, so as to enable electrons to be shared between atoms across the interface could result in an ideal weld. The preparation of surfaces with this degree of precision and cleanliness is not feasible at present, although it is approached in space technology when metals may be in contact in the ultra-high vacuum of outer space. Slight rubbing of surfaces under these conditions can induce welding by satisfying the first two conditions above at limited points of contact, the third being supplied already by the vacuum. While

such conditions of cleanliness and vacuum might be visualized for special micro-welding applications, alternative solutions must be found for practical welding.

The problem of achieving atomic contact between the parts to be joined is solved in one of two ways. Pressure may be applied so that abutting surfaces are plastically deformed giving the required intimacy of contact. The deformation also helps to satisfy the cleaning requirement by rupturing films. With ductile metals the plastic deformation can be accomplished cold, but less malleable metals may be first softened by heat. Alternatively, the surfaces to be joined may be bridged with liquid metal. [3]

Majority of welding processes employ the latter method, and their variety is an indication of the many ways by which it is possible to generate locally the heat required for melting.

The two types of welding process described are fundamentally different, and the division between them forms the first breakdown in the classification of welding processes. Those welding methods employing pressure to deform plastically the faying surfaces are called 'solid-phase' methods. There is no accepted term for the methods in which union is made through liquid metal but they may be called 'liquid-phase' methods.

For some years it has been customary to divide welding processes into 'pressure' and 'fusion' welding methods.

Commercial Arc-Welding Processes [2]

- 1) Shielded Metal-Arc Welding
- 2) Self shielded Flux-cored welding
- 3) Gas Metal-Arc Welding
- 4) Gas Shielded flux-cored
- 5) Gas Tungsten-Arc Welding
- 6) Submerged-Arc welding

Welding may be employed in the fabrication of practically all types of structures. Gas welding is more expensive than arc welding and may cause more buckling & warping when used to weld very thin flat sections unless excessive clamping is

employed. Gas welding is usually specified for metals between 0.25 and 1.5 mm thick, stainless steel frequently being an exception. Arc welding is used in applications where these limitations apply, and in general where high production rates are involved since arc welding is a lower-production-cost process. [2]

Table 3.1: Comparison of welding processes

Process	Advantages	Disadvantages
Resistance Welding	Very flexible, economical, joins three or more pieces with one weld. Properties of joint independent on process. Can join any combination of metals that alloy together	Poor in fatigue Requires expensive equipment must be able to reach both sides of the joints.
Gas Welding	Good control of weld metal. Heat input anneals weld metal and heat affected zone.	High cost, Low production rate Higher heat input; steep temp. gradient. More warpage, distortion etc... Material thicknesses must be nearly equal.
Arc Welding	High production rate minimum distortion low annealing of base metal	Stress concentrations at edges of welds, under cutting overlaps, etc... Likely.

Source: Reference [2]

3.3 JOINING RATE

The total cross-sectional area of metal joined in unit time is suggested as a useful practical method of comparing processes and their performance. For welds in sheet and plate this is conveniently the welding speed in mm/s multiplied by the metal thickness in mm. With fillet welds the factor would be speed x leg length and for spot welds the nugget area at the interface divided by time. For multi-pass welds the speed taken is that based on arc time to complete the joint. Each process and type of joint appears to have a characteristic joining rate independent to a large degree of thickness. Table 3.2 gives typical joining rates for a number of processes, and it is seen that the high heat-input rate processes generally give high joining rates. [2]

TABLE 3.2: TYPICAL JOINING RATES

No.	Weld process	mm²/sec.
1	<i>Oxyacetylene welding, steel</i>	1.6-5.4
2	<i>Manual metal-arc, up to 12.5 mm steel</i>	17-27
3	<i>Manual metal-arc, over 20 mm steel</i>	6.5-9.7
4	<i>Manual metal-arc, vertical welds, steel</i>	3.2-14
5	<i>Submerged-arc, steel</i>	43-86
6	<i>Submerged-arc, high current techniques</i>	107-140
7	<i>Inert-gas metal-arc, backed butts, aluminium</i>	34-41
8	<i>Inert-gas metal-arc, as above, vertical</i>	27
9	<i>Tungsten-arc, butt welds, aluminium</i>	8.6-14
10	<i>High-frequency resistance, aluminium</i>	650-1400
11	<i>High-frequency resistance, copper</i>	375-650
12	<i>High-frequency resistance, steel</i>	650-975
13	<i>Resistance spot weld, steel</i>	43-107
14	<i>Electro-slag (per wire)</i>	16-21
15	<i>Electron-beam</i>	up to 200

Source: Reference [3]

3.4 THE SELECTION OF WELDING PROCESSES

The selection of a welding process can be a difficult matter in which a number of competing factors have to be taken into account.

Weldability is profoundly affected by the process used. Merely changing from one process to another will not remove all problems as every method has its own limitations but at least it is sometimes possible to exchange one set of problems for another which is easier to accommodate. Even a decision on the general arrangement of the design may preclude the use of certain processes.

The selection and use of a process is determined by technical suitability for use on the type of joint required, metallurgical suitability for the material being welded and by the economics of its use.

For many simple structures in mild steel there are no problems in welding and this can obscure the fact that for welding technology as a whole the design, material selection and choice of process cannot be made independently. It is necessary to have experience and knowledge of many factors from the expected service conditions to the facilities and skill available in the workshop where the fabrication is to take place. [3]

STEPS WHICH CAN BE TAKEN TO REDUCE THE NUMBER OF PROCESSES

1. TYPE OF PRODUCT

It is helpful to divide welded fabrications into three classes, structural fabrications, engineering components and semi-finished products.

Structural fabrications are defined as those for which by reason of their size or shape the welding device must be brought to the job. Examples of this type of structure are ships, bridges, building structures, cranes, chemical plant, the larger more complicated pressure vessels, large machine tool frames and automobile bodies.

Engineering components can be defined as more compact constructions which can be taken to the welding machines or installations. Examples of this are valve bodies, hydraulic cylinders, small pressure vessels, electrical parts, rotating machinery, automobile suspension, steering gear and transmission.

Semi-finished products are produced continuously from a fixed installation and include those in which there is continuous weld, for example welded sections, longitudinally and spirally welded tubes, finned tubes and band-saw blades.

The significance of this classification of types of welded fabrication is that structural fabrications inevitably involve a high proportion of manual or semi-automatic welding and this is usually some form of arc welding.

Engineering components can be welded with a wider range of processes, often mechanized arc welding.

Semi-finished products employ continuous welding processes in automatic machines with highly developed material feeding equipment.

2. PRODUCTION FACILITIES

Another useful first step is to consider the extent to which the equipment and skills already available in the workshop can be employed. If only one or two of the designs have to be fabricated it will be probably be necessary to make the choice from those processes already in use in the shop where the fabrication is to take place. Should further similar work be anticipated in the future, however, additional plant could be considered. A large job may make the acquisition of new plant feasible even if it is subsequently redundant.

In all the above considerations the cost per unit production is important factor. Plant costs must be spread over the number of units produced.

3. METAL THICKNESS

Material thickness is the next most important consideration. For example sheet metal can not be welded by electro-slag but it might be welded by resistance spot, inert-gas tungsten-arc or dip transfer CO₂ welding. Metal 50 mm thick could not be welded by resistance spot welding but electro-slag or submerged-arc would be suitable processes.

There tends to be preferred thickness range for each process just as there is a preferred operating range for an individual piece of welding equipment. Operating at the extremes of a range requires closer tolerances on all variables, increases the risk of defects and puts up costs.

4. MATERIAL

Material type must also be taken into account. While mild steel can be welded readily by many processes, aluminium alloys can only be joined by a more limited range, for example flux-shielded processes are avoided because of the corrosive nature of fluxes for aluminium and the 'spattering' type of metal transfer in such arcs.

4.1. CRACKING

The higher the carbon equivalent and the greater the thickness of the joint the greater is the risk of hydrogen cracking in the heat-affected zone. Much is now known about the control of this problem which in practical terms means selecting

a welding process and consumables giving low weld hydrogen content, and limiting the cooling rate by preheat and/or using more than a prescribed minimum arc energy input per unit length of weld.

4.2. POROSITY

Porosity in weld metal arises in three ways:

- a) The generation of gas within the weld metal by chemical reactions, as may happen when a weld pool is inadequately deoxidized because an unsuitable filler wire is used or excessively rusty or scaled plate is welded
- b) The rejection from solid solution of gas dissolved within the molten weld metal. This occurs with nitrogen absorbed from the atmosphere in CO₂ welding steel or hydrogen from the wire surface in inert-gas metal-arc welding of aluminium. Fine distribution porosity is a feature of gas metal-arc welding aluminium whereas with inert-gas tungsten-arc process this type of porosity is rare. There are three possible reasons for this, the smaller surface-to-volume ratio of the larger-diameter filler wire used in tungsten-arc welding, the evaporation of hydrogen compounds from the wire at the edge of the arc or the generally less-rapid solidification than gas metal-arc which allows the gas time to nucleate and escape.
- c) The entrainment or trapping of gas by physical means. Two types of trapped porosity are encountered. With close square butt joints made by many processes heat spreads ahead of the weld pool causing expansion, and therefore pressure, forcing the joint faces together. Local pressure welding can occur at the leading edge of the weld pool any roughness of the joint faces will leave small cavities which become sealed. Air or shielding gas trapped in these cavities then forms pores in the weld pool which may be swept to the edges of the weld pool where they are trapped on solidification. The more accurately the edges are prepared the more likely it is that this form of porosity occurs. A few degrees of inaccuracy in the edge preparation prevents trapping and the use of a different angle to the welding torch to change the direction of metal flow in the pool, should

alleviate this form of porosity. Another form of trapped porosity occurs in the root of gas metal-arc welds. This form of porosity is insufficiently recognized although it is quite common. With the gas metal-arc process a high welding current and argon-rich shielding gas results in a deep 'finger type' penetration and a turbulent weld pool. Shielding gas can be entrained and becomes trapped as isolated, often elongated pores in the point of the 'finger' at the weld root. This type of porosity has bedeviled the gas metal-arc welding of stainless steel for years.

4.3. WELD AND HEAT-AFFECTED ZONE TOUGHNESS

To give an assurance against failure by brittle fracture most structures of any importance have a minimum requirement for notch toughness placed upon the joint as a whole, that is, both weld metal and heat-affected zone. A survey of notch toughness values across a welded joint show that the lowest values are recorded at the center of the weld and a position just inside the heat-affected zone. Weld-metal toughness is influenced by wire composition, dilution, flux type, energy input per unit length and the number of weld runs.

In descending order of toughness in the weld metal the common processes can be arranged as follows, manual metal-arc, cored-wire, submerged-arc, electro-gas and electro-slag. The most important factors in determining weld-metal toughness are probably wire and flux chemistry but various process variables summed up in the heat input per unit length parameter are also important. After composition, heat input is the dominant influence in the heat-affected zone of a weld, high-speed minimum heat input per length being preferred.

4.4. CORROSION AND OTHER HEAT-AFFECTED ZONE PHENOMENA

Precipitation, over-aging, and weld decay are all phenomena occurring in the heat-affected zone which are time-temperature dependent, and are, therefore, affected by welding process and heat input.

When employing multi-pass welds the effect of each pass can be additive but if corrosion resistance is being considered at one point, for example the root of a butt weld, the upper passes will have less effect. Clearly it is an advantage in

exacting service conditions to use a process with a high joining rate such as electron-beam with possibly one of the lowest heat inputs per unit length as well as the capacity to make single pass welds of considerable thickness.

5. JOINT TYPE AND POSITION

The shape or type of the joint is a further factor limiting the choice of process, for example friction welding cannot be used for making long butt welds in plate but it is ideal for making joints in bar stock. Submerged-arc welding which is suitable for making long butt welds cannot be used for welding small-diameter tube where tungsten-arc could be ideal. Table 3.3 gives a brief summary of the application range of the different processes.

Another important consideration is access to the joint. If manual welding is being employed there must be sufficient space around the joint for the welder to move and see the joint line. [3]

Table 3.3: Main processes for different shapes of joints

No.	Process	Sheet & plate	Large pipe & cylinder	Butts		Fillets or T-joints	Attachments
				Tubes	Bar		
1	Plasma	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>			
2	Resistance spot	<input type="checkbox"/>	<input type="checkbox"/>				<input type="checkbox"/>
3	Resistance seam	<input type="checkbox"/>	<input type="checkbox"/>				<input type="checkbox"/>
4	Tungsten-arc	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/> ^a	<input type="checkbox"/> ^a
5	Oxyacetylene	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>			
6	Gas metal-arc	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/> ^a
7	Metal-arc	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/> ^a
8	Cored-wire	<input type="checkbox"/>	<input type="checkbox"/>			<input type="checkbox"/>	
9	Submerged-	<input type="checkbox"/> ^b	<input type="checkbox"/>			<input type="checkbox"/>	

				Butts		Filletts or T- joints	Attach- ments
	arc						
10	Electro-gas	<input type="checkbox"/> c				<input type="checkbox"/>	
11	Electro-slag	<input type="checkbox"/> c				<input type="checkbox"/>	
12	Electro-beam	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/> d	<input type="checkbox"/> d	<input type="checkbox"/>	<input type="checkbox"/>
13	Flash			<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>
14	Friction			<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>
15	Resistance butt			<input type="checkbox"/>	<input type="checkbox"/>		
16	Diffusion			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
17	Projection					<input type="checkbox"/>	<input type="checkbox"/>
18	Tungsten-arc spot						<input type="checkbox"/>
19	Gas metal- arc spot						<input type="checkbox"/>
20	Thermit				<input type="checkbox"/>	<input type="checkbox"/>	

Source: Reference [2]

Note:

^a *Light gauge only*

^b *Mainly in flat position*

^c *Mainly in vertical position*

^d *Work revolved under fixed welding station*

It is usually desired to turn a welded fabrication into a position which will allow flat position or down hand welding as welding speeds are then at a maximum. Welding position is, therefore, a limiting factor for large structures which can not be turned easily to the best welding position. An oil storage tank, for example, requires some welds to be made in vertical position and others in the horizontal-vertical position. It is also important to know if the welding can be carried out in a welding shop or if it must be done on site in the field. Site welding generally means difficult working conditions, a lower standard of fit-up of work and

increased problems in control. Simple processes function best. Gas-shielded processes require special protection from draughts and all processes require dry, clean conditions.

When the highest standards of weld quality are necessary the joint must be manufactured with quality assurance and this will mean that quality control and non-destructive testing must be applied. Not all joints can be inspected by the common techniques of radiography or ultrasonic. Butt joints are usually easy to inspect by both methods but some fillet joints can not be inspected by radiography and ultrasonic may also be unsuitable if there is not a wide enough flat area near the weld on which to place the probe. Other complicated joints with many surfaces from which the ultrasound may be reflected are also impossible to inspect because spurious reflections confuse the operator. Some solid-phase welds are extremely difficult to inspect and it is necessary to employ quality assurance procedures and in-process monitoring. Depending on service requirements and the need for inspection it may be necessary to modify the joint design or even change the process. [3]

CHAPTER FOUR

4 INSPECTION AND TESTING OF WELDS

During the process of welding, faults of various types may creep in. Some, such as those dealing with the quality and hardness of the weld metal, are subjects for the chemist and research worker, while others may be due to lack of skill and knowledge of the welder. These, of course, can be overcome by correct training (both theoretical and practical) of the operator.

In order that factors such as fatigue may not affect the work of a skilled welder, it is evidently necessary to have means of inspection and testing of welds, so as to indicate the quality, strength and properties of the joint being made.[1]

4.1 INSPECTION DURING WELDING

Metal arc welding: the chief items to be observed are: (1) rate of burning of rod and progress of weld, (2) amount of penetration and fusion, (3) the way the weld metal is flowing (no slag inclusions), (4) sound of the arc, indicating correct current and voltage for the particular work.

Oxy-acetylene welding: the chief items are: (1) correct flame for the work on hand, (2) correct angle of blowpipe and rod, depending on method used, (3) depth of fusion and amount of penetration, (4) rate of progress along the joint.

The above observations are a good indication to anyone with experience what quality of weld is being made, and this method furnishes one of the best ways of observing the progress of welders when undergoing training.

4.2 INSPECTION AFTER WELDING

Examination of a weld on completion will indicate many of the following points:

1. Has correct fusion been obtained between weld metal and parent metal?
2. Is there an indentation, denoting undercutting along the line where the weld joints the parent metal (line of fusion)?
3. Has penetration been obtained right through the joint, indicated by the weld metal appearing through the bottom of the V on a single V or U joint?

4. Has the joint been built up on its upper side (reinforced), or has the weld a concave side on its face, denoting lack of metal and thus weakness?
5. Does the metal look of close texture or full of pinholes and burnt, denoting incorrect flame?
6. In arc welding has spatter occurred, indicating too high a current or too high a voltage across arc or too long an arc?
7. Are the dimensions of the weld correct, tested, for example, by gauges.

A study of the above will indicate to an experienced welder what faults, if any, exist in the work and then provide a rapid and useful method of ensuring that the right technique of welding is being followed.

Visual inspection, however, has several drawbacks. It is obviously be impossible to observe by visual means whether penetration has occurred at the bottom of the V except at the two ends.

A great variety of methods of testing welds are available.

There are two types of welding tests:

1. Non-destructive
2. Destructive

Destructive tests are usually carried out either on test specimens made specially for the purpose, or may even be made on one specimen taken as representative of several similar ones.

Destructive tests are of greatest value in determining the ultimate strength of a weld and afford a check on the quality of weld metal and skill of the operator.

4.3NON-DESTRUCTIVE TESTS

1. Visual inspection (including use of a penetrant fluid).
2. Magnetic
 - a. iron filings in paraffin (magnetic fluid),
 - b. search coil
3. Sound (acoustic) methods:
 - a. hammer
 - b. hammer and stethoscope

4. X-ray
5. Gamma ray
6. Ultrasonic
7. Application load

4.3.1 VISUAL INSPECTION (PENETRANT FLUID)

Surface defects can be identified by painting or aerosol spraying on a penetrant fluid, wiping clean, and then a developer which shows up, visually or by ultra-violet light, defects found by the fluid.

4.3.2 MAGNETIC TESTS

Iron filings in an extremely finely divided state (colloidal) are suspended (or mixed) in paraffin (often termed magnetic fluid).

The specimen under test is highly magnetized, usually by magnetizing coils, or by being placed in a strong magnetic field, and the fluid is then painted on the weld, which must have a machined or polished surface. If there is any crack in the metal, an alteration in the magnetic field (or flux) occurs at the crack, which is in reality a minute air gap. As a result, the finely divided particles of iron cling to the edges of the crack and show it up as a dark hair.

Its back draws are that:

1. It can only be applied to iron and steel, as these are the only magnetic substances
2. It only shows up surface cracks
3. The specimen must be machined or polished and magnetized

4.3.3 X-RAY METHOD

X-rays are electro-magnetic radiations of short wave-length and they can penetrate solid substances, but, in doing so, a certain proportion of the rays are absorbed. The amount of absorption depends on the thickness of the substance and on its density. The denser and thicker the substance, the smaller the proportion of rays which get through. Certain substances, such as calcium

tungstate and barium platino-cynaide, become fluorescent or luminous when X-rays strike them. If a screen is coated with one of these substances and the rays fall on it, the sensitized screen becomes brightly illuminated. If now an object, such as a piece of steel, is placed in the path of the rays in front of the screen, a shadow of the object will be thrown on the screen, and if the object is of the same thickness and density throughout, the shadow will also be of the same degree of darkness over all its surface. If, however, any holes or cavities exist in the steel, the rays will be less absorbed at these points and the shadow will be more brightly illuminated at these spots.

In the same way films covered with silver halides are affected by light. Thus if an X-ray film is put in place of the sensitive screen in the above, a 'shadowgraph' of the object will appear when the film is developed. Films are used more than the screen method, because they provide a permanent record of the shadow which can be carefully studied.

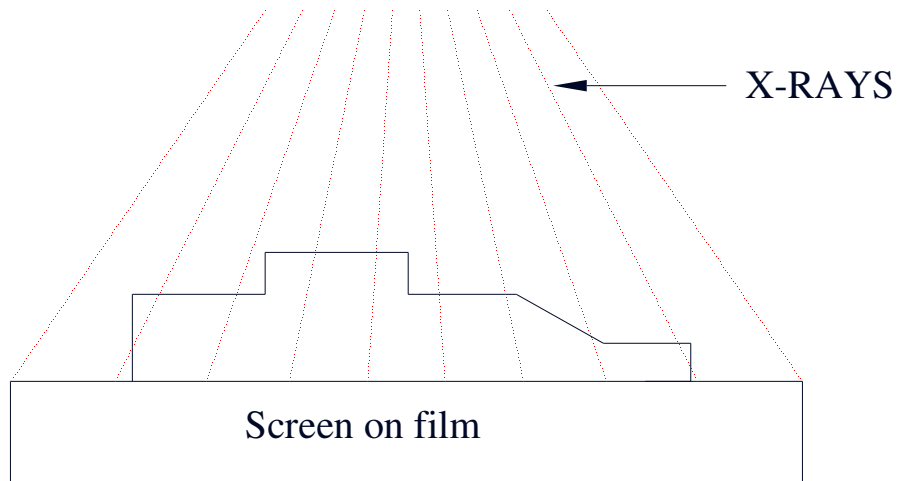


Fig. 4.1

Now, just as in photography an incorrectly exposed film will possess no detail, so with an X-ray photograph no detail of defects in the object can be observed unless correct exposure is given. This is entirely a matter of practice.

In order to make sure that we are getting a correctly exposed negative, so that even the smallest defects will be shown up, it is usual to place a penetrometer, which is a small strip of cutting of the same material as the object (steel for example) and about $1/100$ to $2/100$ of its thickness, on upper surface next to X-ray tube, as shown in Fig. 4.2a.

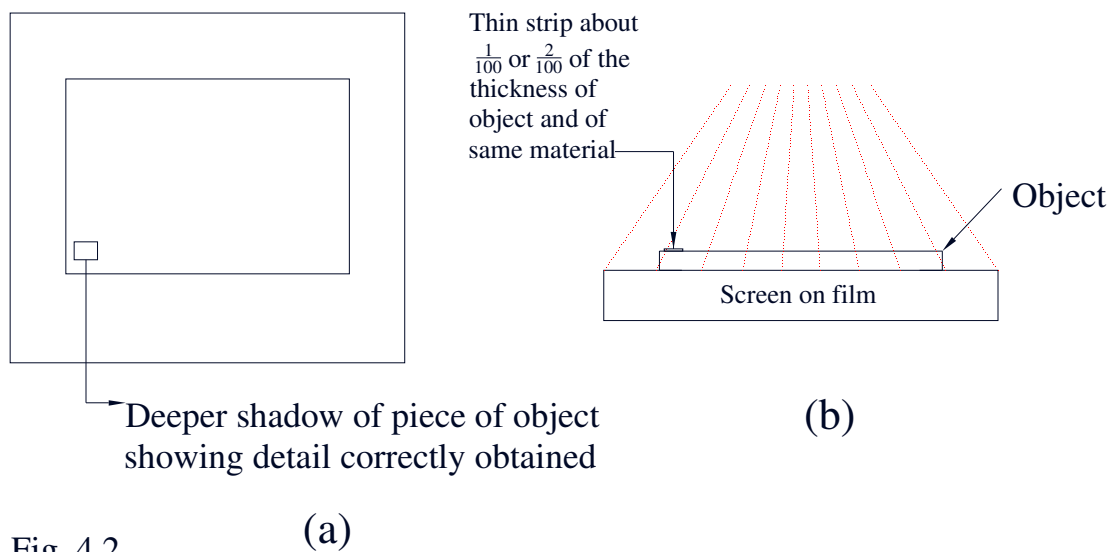


Fig. 4.2

If this now appears as shown in Fig. 4.2b, as a shadow on the negative, we are sure that any defects or holes of the size $1/100$ to $2/100$ of the thickness of the object will be indicated.

Great practice is necessary to interpret the X-ray films of welds correctly and to distinguish between various defects show up as shadows. Gas holes causing porosity are usually regular in shape, while any included slag is usually very irregular. In this way, we can determine whether penetration to the full depth required has been obtained, and whether there are regions of entrapped slag, blowholes or other porous defects. In addition, any defects, such as contraction cracks, will also show up clearly.

The X-raying of butt welds is comparatively straightforward, but with fillet welds special methods have to be adopted, and often more than one photograph taken in different directions.

Finally, the method of X-ray inspection of pressure vessels, such as boilers, may be mentioned. During the welding operation on the boiler, one or more test pieces are made by the welder, using the same technique exactly as on the boiler, the test pieces being of the same metal and thickness as the boiler itself. The weld on the boiler is X-rayed along its whole length and the test pieces are also X-rayed. A comparison of the negatives will indicate how closely the structure of the test pieces compares with that of the boiler itself and if (as is usually the case) this is very close, it can reasonably be supposed that the boiler weld would behave as the test pieces under test. The test pieces are then tested by the usual methods and finally tested to destruction. This affords an excellent indication as to the probable behavior of the boiler weld under test. The American Society of Mechanical Engineers (ASME) specifies the above test in their boiler Code. [1]

4.3.4 ULTRASONIC TESTING

Ultrasonic testing employs waves above the frequency limit of human audibility and usually in the frequency range 0.6 to 5 MHz. A pulse consisting of a number of these waves is projected into the specimen under test. If a flaw exists in the specimen an echo is reflected from it and from the type of echo the kind of flaw that exists can be deduced.

The equipment comprises an electrical unit which generates the electrical oscillations, a cathode ray tube on which pulse and echo can be seen, and probes which introduce the waves into the specimen and receive the echo. The electrical oscillations are converted into the ultrasonic waves in a transducer which consists of a piezo-electric element mounted in a Perspex block to form the probe, which, in use, has its one face pressed against the surface of the material under test. When a pulse is injected into the specimen a signal is made on the cathode ray tube. The echo from a flaw is received by another probe,

converted to an electrical e.m.f. (which may vary from microvolt to several volts) by the transducer and is applied to the cathode ray tube on which it can be seen as a signal displaced along the time axis of the tube from the original pulse (Fig. 4.3a).

The first applications of ultrasonic to flaw detection employed longitudinal waves projected into the specimen at right angles to the surface (Fig. 4.3b). This presented problems because it meant that the weld surface had to be dressed smooth before examination, and more often than not the way in which the flaw oriented, as for example, lack of penetration, made detection difficult with this type of flaw. The type of wave used to overcome these disadvantages is one which is introduced into the specimen at some distance from the welded joint and at an angle to the surface (e.g. 20°) and is known as a shear wave. The frequency of the wave (usually 2.5 and 1.5 MHz for butt welds), the angle of incidence of the beam, the type of surface and the grain size, all affect the intensity of the echo which is adjustable by means of a sensitivity control. The reference standard on which the sensitivity of the instrument can be checked consists of a steel block 300 x 150 x 12.7 mm thickness with 1.6 mm hole drilled centrally and perpendicularly to the largest face 50.8 mm from one end. Echoes are obtained from the hole after 1, 2 or 3 traverses of the plate (Fig. 4.3c) and from the amplitude of the echo the sensitivity from a hole of known size can be checked. [1]

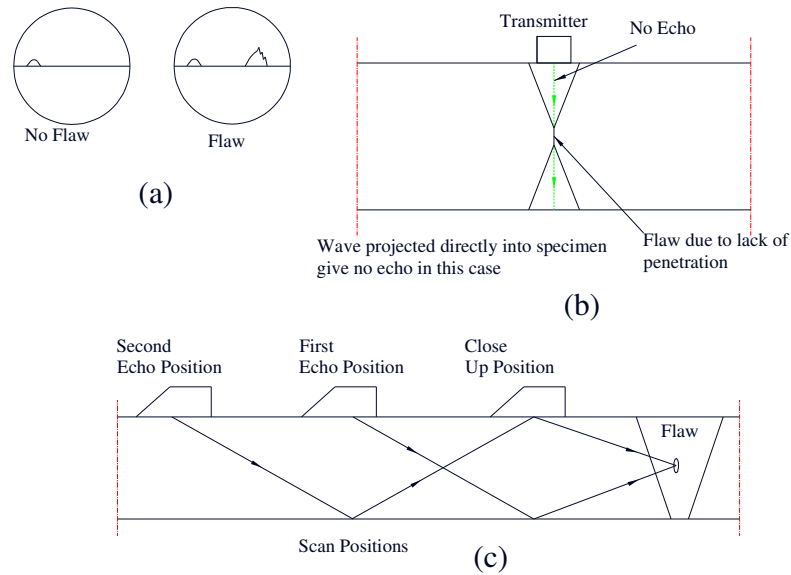


Fig. 4.3(a) (b) (c)

Three types of probe are available:

1. A single probe which acts as transmitter and receiver, the same piezo-electric elements transmitting the pulse and receiving the echo. The design of the probe is complicated in order to prevent reflections within the Perspex block confusing the echo.
2. The twin transmitter-receiver probe in which transmitter and receiver are mounted together either side by side or one in front of the other but is quite separate electrically and ultrasonically so that there is no trouble with interference with the echo. This type is the most popular.
3. The separate transmitter and receiver each used independently (two-handed operation). (Fig. 4.3d).

To make a 'length scan' of the weld the transmitter-receiver unit is moved continuously along a line parallel to the welded seam so that all points of the whole area of the welded joint are covered by the scanning beam and care must be exercised that by the use of too high a spread of the beam, double echoes are not obtained from a single flaw. It is evident that varying the distance from the weld to the probe varies the depth at which the main axis of the beam crosses

the welded joint and moving the probe at right angles to the line is thus known as depth scan. A spherical flaw will have no directional characteristics and a wave falling upon its center will be reflected along the incident path, the amplitude of the echo depending upon the size of the flaw. Cylindrical flaws behave in the same way but in the case of a narrow planar flaw it is evident that optimum echo will be received when the crack is at right angles to the wave and there will be no echo when the crack lies along the wave, but if the probe is moved to the first echo position the crack is no longer lying along the beam.

The probes must make good contact with the specimen and on slightly curved surfaces a thin film of oil is used to improve the contact. On surfaces with greater curvature, as for example when investigating circumferential welds on drums, curved probes are used.

We have only considered the essential points of ultrasonic testing and it must be emphasized that there is a considerable amount of theory involved in the connection between distance of transmitter from the weld in terms of the beam angle, etc., and that a great amount of practice is required to interpret correctly the echoes received and from them decide the nature and position of the flaw. [1]

SAFETY PRECAUTIONS

Factory regulations demand that personnel operating X-ray or gamma-ray equipment must either wear film badges or carry dosimeters. Film badges are supplied by a special service which processes them after they have been worn for a specified time and reports on the amount of radiation that the wearer has received. One type of dosimeter indicates the radiation dose received by checking it on a master control. Another type indicates the dose visibly on a built-in optical system. A geiger counter indicating the intensity of radiation is used to indicate the effectiveness of shielding and the limits of the area in which it is safe for personnel to work. [8]

4.3.5 APPLICATION OF LOAD

An illustration of this method is furnished by the hydraulic test on boilers. Water is pumped into the welded boiler under test (the safety valve if fitted having been clamped shut) to a pressure usually 1 ½ to 2 times the working pressure. Should a fault develop in a joint, the hydraulic pressure rapidly falls without danger to persons near, such as there would have been if compressed air or steam had been used.

In the same way, partial compressive or tensile loads may be applied to any welded structure to observe its behavior. The method adopted will, of course, depend on the nature of the work under test. [1]

4.4 DESTRUCTIVE TESTS

These can be divided as follows:

1. Test capable of being performed in the workshop.
2. Laboratory tests, which may be divided as follows
 - a. Microscopic and macroscopic
 - b. Chemical, analytical and corrosive
3. Mechanical

4.4.1 WORKSHOP TESTS

These are usually used to break open the weld in the vice for visual inspection. When operators are first learning to weld, this method is very useful, because as a rule the weld contains many defects and, when broken open, these can quickly be pointed out. Little time is thus lost in finding out the faults and rectifying them. As the welding technique of the beginner improves, however, this test becomes of much less value. Obviously much will depend on the actual position of the specimen in the vice, whether held on the joint or just below it. Also on the hammering, whether heavy erratic blows are used or a medium-weight, even hammering is given. In addition, if the weld metal is stronger than the parent metal, fracture may occur in the parent metal and thus the weld itself has hardly been tested.

Another useful method for determining the ductility of the weld is to bend the welded specimen in the vice through 180 ° with an even bending force. Any cracks appearing on the weld face will indicate lack of ductility.

A useful workshop test, for use in the case in which the welded parts have to be heated up or even forged after welding, consists of actually forging a test specimen after welding. It is always advisable to apply the tests given also, such as tensile, in order to obtain the ultimate strength of the weld.

Workshop tests are very limited, and their chief advantage is the little time taken to perform them. They are useful during training of welders, but little knowledge of the weld can be gained from them. The visual method, as previously explained, is a valuable addition to the workshop methods given above. [1]

4.4.2 MECHANICAL TESTS

These may be classified as follows:

1. Tensile
2. Bending
3. Impact: Charpy and Izod
4. Hardness:
 - a. Brinell,
 - b. Rockwell,
 - c. Vickers Diamond Pyramid
 - d. (Hardness Vickers HV) and
 - e. Scleroscope
5. Fatigue : Haigh
6. Cracking: Reeve

4.4.2.1 TENSILE TEST OF A WELDED JOINT

It is evident that a tensile test on a welded joint is not quite similar to a test on a homogenous bar, and the following considerations will make this clear. The steel weld metal may be strong, yet brittle and hard. When tested in the machine, the specimen would most probably break outside the weld, in the parent metal, whereas in service due to its brittleness, failure might easily occur in the weld

itself. The result of this test gives the tensile strength of the bar itself and indicates that the weld is sound.

If the weld metal is softer than the parent metal, when tested the weld metal itself will yield, and fracture will probably occur in the weld. Because of this, the elongation of the specimen will be small, since the parent bar will have only stretched a small amount, and this would lead to the belief that the metal had little elasticity. Quite on the contrary, however, the weld metal may have elongated by a considerable amount, yet because of its small size in comparison to the length of the specimen the actual elongation observed is small. Great care must therefore be taken to study carefully the results and to interpret them correctly, bearing in mind the properties which it is required to test.

A tensile test on an all-weld metal specimen prepared as previously explained indicates the strength and ductility of the metal in its deposited condition and is a valuable test.

A very useful form of test which is used nowadays is that known as the longitudinal test. In this test the weld runs along the length of the test piece (Fig. 4.4). As the load is applied, if the weld metal is ductile, it will elongate with the parent metal and is placed in the machine so that the load is applied longitudinally to help to share the load. If, on the other hand, it is brittle, it will not elongate with the parent metal but will crack. Should the parent metal be of good quality and structure, the cracks will be confined to the weld metal mostly and will merely increase in width. If the parent metal is not of such good quality, the cracks will extend into the parent metal and breakage will occur with little elongation of the specimen. This test therefore indicates the quality of the parent metal as well as that of the weld metal.[1]

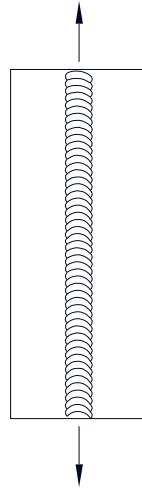


Fig. 4.4. Longitudinal tensile test of welded specimen

4.4.2.2 BEND TEST (FOR DUCTILITY OF A SPECIMEN)

In this test the bar is prepared by chamfering the edges to prevent cracking (if it is of rectangular section), and is then supported on two edges and loaded at the center.

The method of determining the ductility of the bar from this test is as follows. Lines are scribed on the machined or polished face of the specimen parallel and equidistant to each other across a width of about 150 to 250 mm. As the load is applied, the increase in distance between the scribed lines is measured, and this increase is plotted vertically against the actual position of the lines horizontally.

Now consider the test applied to a welded joint and let the weld be placed in position under the applied load. There are now two different metals to be considered, since the weld metal might have quite different properties from those of the parent metal.

If the load is applied and the yield point of the weld metal is greater than that of the parent bar, plastic yield or bend will occur in the bar and as the load is increased the bar bends plastically. During this bending, if the yield point of the weld metal is reached; the weld metal will flow or yield somewhat, but in any case most of the bend is taken by the bar. If the yield point of the weld metal is not reached, then the entire bend will be taken by the bar.

If however, the yield point of the weld metal is lower than that of the bar, the weld metal will first bend plastically and will continue to do so, plastic deformation occurring long before the yield point of the bar is reached.

On such a small area as the weld metal has fractured will occur in the weld metal at a small angle of bend.

Since the weld metal is almost always harder or softer than the parent metal the bending will not occur, therefore, equally in the weld and parent metal, and as a result the chief value of this test is to determine whether any flaws exist in the weld. Otherwise its value as a test of ductility of a welded specimen is very limited.

If the weld is placed so that its face is under the central applied load, fracture will occur at the root of the weld if the penetration is imperfect. [1]

4.4.2.3 IMPACT TESTS

We have seen when discussing notch brittleness in steel that localized plastic flow at notch may cause cracking and that the transition from ductile to brittle state is affected by temperature, strain rate and the occurrence of notches. It should be noted that as there is no ductile-brittle transition with aluminium, impact tests are performed to a lesser degree with aluminium than with steel. Serrations, tool marks, changes of section and other discontinuities on the surface of metals that are met with in service reduce their endurance so that the term 'notch sensitivity' is applied to the degree to which these discontinuities reduce the mechanical properties. This is an important consideration in welding because for example any reduction in section due to undercut along the toes of butt welds and in the vertical plate in HV fillets reduces the mechanical properties of the structure.

To determine the notch brittleness (or notch toughness), impact tests are performed on specimens prepared with a notch of precise width, depth and shape, and the resistance which the specimen offers to breaking at the notch

when hit by a striker moving at a given velocity and having a given energy is a measure of the notch brittleness.

The two main tests: Charpy and Izod, employ a swinging pendulum to which a slave pointer is attached. This moves over a scale calibrated in joules as the pendulum swings and stays at the impact value of the test, being afterwards reset by hand. The pendulum tip (or bob) incorporating the striker hits the notched specimen at a given velocity and with a given energy (measured in joules). If no specimen were present the pendulum would swing unhindered to the zero position on the scale, but since energy is lost in breaking the specimen the pointer will take up a position say x joules on the scale. This is the impact value for the specimen at the particular temperature and represents the energy lost by the pendulum in breaking the specimen.

Impact tests are being increasingly used at sub-zero temperatures in order to give indications and possibilities of brittle fracture. Diethyl ether and liquid nitrogen are used to obtain temperatures down to -196°C using a copper-constantan thermo-couple for temperature measurement. [1]

4.4.2.4 CHARPY TEST

This test may be either with a V or a U section notch, the specimen and notch sizes being shown in Fig. 4-5. The V notch test is becoming increasingly used in Britain and is the test required for impact values in BS 639-Covered electrodes for the MMA welding of carbon and carbon-manganese steels.

The specimen is supported squarely at its two ends by machine supports, the notch being centrally placed by means of small tongs (Fig. 4.6). The pendulum is raised to the test height and the pointer indicates 300J on the scale. A hand lever is operated, the pendulum swings and the striker hits the specimen exactly on the side behind the notch. Energy is absorbed in fracturing the specimen and the pointer swings to say x joules, on the scale this being the Charpy value at the particular temperature on the 300J scale for either V or U notch, whichever was chosen. [1]

4.4.2.5 IZODE TEST

This test is performed on a specimen with a V notch and of dimensions as in Fig. 4.7. The specimen is mounted vertically in a groove in the vice wedge block assembly which is tightened by hand wheel.

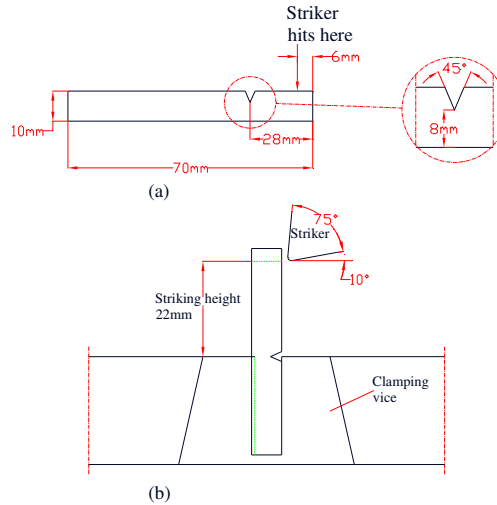


Fig. 4.7. The izode test (single notch)

The V notch is located facing the striker and with the base of the V exactly in line with the top edge of the vice, and is lined up with a small hand jig. The striker hits the specimen at the striking height 6 mm above the V notch (Fig. 4.7). [1]

4.4.2.6 FATIGUE TEST

If a specimen is subject to a continuously alternating set of load operating for long periods, the specimen may fail due to fatigue of the molecules, and the magnitude of the force under which it may fail will be much less than its maximum tensile or compressive strength. The forces applied rise to a maximum tension, decrease to zero, and rise to a maximum compression and decrease again to zero.

In the Haigh tests, a soft-iron core or armature vibrates between the poles of an electro-magnet carrying alternating current, and is connected to the specimen under test. As alternating current is passed through the coil, the armature

vibrates at the frequency of the supply (usually 50 Hz) between the poles, and the welded specimen is thus subjected to alternating load at this frequency.

The drawback to this test is that at 3000 reversals per minute an endurance test of 10,000,000 reversals would take about 56 hours and a complete endurance test will take many days.

The latest type of electromagnetic fatigue tester gives approximately 17000 reversals per second, and thus the required tests can be performed in a fraction of the time and the machine automatically shuts off when failure occurs.

The pick-up which causes the vibration is controlled from an oscillator and non-magnetic metals can also be tested.

In the Wohler test, the specimen is gripped at one end in a device like a chuck and the load is applied at the other end by fixing it to a bearing, as shown in Fig. 4.8. When the chuck rotates, the specimen is continuously under an alternating tension and compression, tension when the face of the weld is uppermost, as shown, and compression when it is below. If the load applied is great, difficulty is experienced by it pulling the specimen out of balance. These out-of-balance forces then increase the forces on the specimen, and we are unable to tell the load under which the weld failed. This can be overcome, however, by a slight modification of the machine having a bearing at each side of the joint under test and the load applied between the bearings, but the test remains the same. In conducting a fatigue test, a certain load is placed on the specimen, and this produces a certain stress. Suppose the stress produced is 140N/mm^2 ; this stress varies from zero to 140 N/mm^2 tensile stress, then back to zero and to 140 N/mm^2 compressive stresses and back to zero. This is a complete cycle.

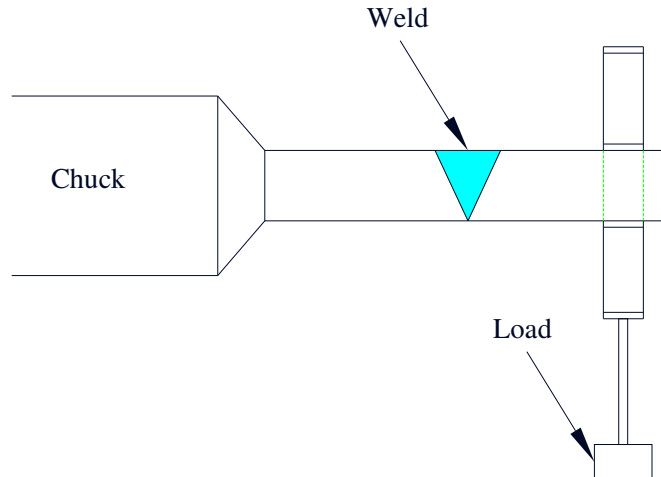


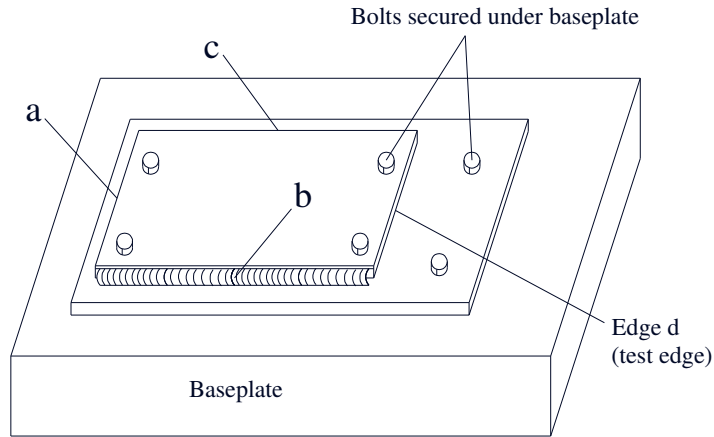
Fig. 4.8. Illustrating principle of Wohler test

Fatigue tests are extremely useful for observing the resistance to fatigue of welded shafts, cranks and other rotating parts, which are subjected to varying alternating loads. They also provide a method of comparing the resistance to fatigue of solid drop forged and welded fabricated components. [1]

4.4.2.7 CRACKING (REEVE) TEST

This is used in the study of the hardening and cracking of welds and is of especial value in ascertaining the weldability of low-alloy structural steels and high tensile steels, which as before mentioned are prone to harden and develop cracks on cooling. A 150 mm square plate of the metal to be welded is placed on another larger plate of the same metal and the two are firmly secured to a heavy bed plate, 50 mm or more in thickness, by means of bolts shown in Fig. 4.9.

Edges **a**, **b** and **c** are then welded with any selected electrode, thus firmly welding the two plates together, and they are then allowed to cool off. Edge **d** is the one on which the test run is to be deposited using the electrode under test, and evidently since the two plates are completely restrained in movement, any tendency to crack on cooling will show in the weld on edge **d**.



Edges a, b, & c
welded

Fig. 4.9. Reeve test

After cooling, the bolts are removed and the weld examined by previously described methods for cracks. Sections can then be sawn off from the plate, the hardness of the weld tested at various points, and sections etched and examined microscopically.

It can be seen from this outline of available tests for welds that the particular test chosen will depend entirely upon the type of welded joint and the conditions under which it is to operate. These conditions will govern the tests which must be applied to indicate the way in which the weld will behave under actual service conditions. [1]

Table 4.1: Summary of type of weld testing [3]

EQUIPMENT	APPLICATIONS	ADVANTAGES	LIMITATIONS
Leak Testing			
<i>Exact equipment depends upon the method used. Generally needs equipment capable of inducing a pressure differential and some form of detection device capable of sensing the leak. Some applications require special fluids such as helium.</i>	<i>Welds that have defects extending through the weld volume.</i>	<i>Many components can be inspected in "real time" along with a proof test. Some applications require very little operator training. Test results are usually obtained fast. Certain processes can be automated, for example, soft drink cans tested at 350-400 per min.</i>	<i>Some methods require special facilities and time-consuming inspection. Applications requiring high levels of sensitivity usually are uneconomical and may require personnel with special training.</i>
Visual Inspection			
<i>Magnifiers; projectors; other measuring equipment such as rulers, micrometers. Optical comparators; light source including ultraviolet light.</i>	<i>Welds with surface defects.</i>	<i>Economical and fast. Needs relatively little training and little equipment for most jobs.</i>	<i>Limited to external or surface conditions only. Limited by inspector's eyesight.</i>
Gamma Radiography			
<i>Gamma-ray source (radioactive isotopes), gamma-ray camera, projectors, film holders, films, lead screens, film processing equipment, film viewers, exposure facilities, radiation monitors.</i>	<i>Most weld discontinuities including cracks, porosity, and lack of fusion, incomplete penetration, slag, as well as corrosion and fit-up defects, wall thickness, dimensions.</i>	<i>Permanent record so that other people can use data later on. Gamma-ray source can be put inside an accessible weld such as pipes and vessels for unusual radiographic techniques. Energy efficient source requires no outside energy to produce gamma rays.</i>	<i>Radiation is a safety hazard. Requires special facilities or area where personnel are monitored. Gamma source must be replaced periodically. Wavelength of radiation source cannot be adjusted. Gamma source must be licensed. Requires highly skilled</i>

(...con't) Table 4.1: Summary of type of weld testing [3]

			<i>operator and data interpreter.</i>
		X-Radiography	
<i>X-ray sources (from high voltage x-ray machine). Electrical power source for x-ray machine, same general equipment used with gamma-ray sources.</i>	<i>Same applications as above.</i>	<i>Adjustable energy levels, generally produces higher quality radiographs than gamma radiation. Offers permanent film record as does gamma radiation.</i>	<i>High initial cost for equipment. Not generally considered portable. Radiation hazard. Skilled operator and interpreter needed.</i>
		Ultrasonic Testing	
<i>Pulse-echo instrument capable of exciting a piezoelectric material and generation ultrasonic energy within a workpiece, and a suitable cathode-ray tube oscilloscope capable of displaying the magnitude of received sound energy.</i>	<i>Most weld discontinuities including cracks, slag, lack of fusion, lack of bond, thickness. Some mechanical property data can be calculated using this test.</i>	<i>Most sensitive to planar (flat) defects. Test results are known quickly and equipment is portable. Most ultrasonic flaw detectors do not require electrical power outlet. They can use batteries. High penetration capability.</i>	<i>Surface condition must be suitable for coupling with transducer. Coupling liquid needed. Welds may be difficult to inspect. Reference required. Skilled operator and data interpreter needed.</i>
		Magnetic-Particle Testing	
<i>Prods, yokes, coils suitable for inducing magnetism into the test workpiece. Power source, magnetic powders; some applications require special equipment.</i>	<i>Most weld discontinuities open to the surface and some large voids slightly below the surface. Most suitable for cracks.</i>	<i>Economical and fast. Inspection equipment is portable. Unlike dye penetrants, magnetic particle can detect some subsurface defects.</i>	<i>Must be applied to magnetic materials. Parts must be cleaned before and after inspection. Coatings will mask rejectable defects. Some applications require parts to be demagnetized after inspection. Magnetic-particle inspection requires electrical</i>

(...con't) Table 4.1: Summary of type of weld testing [3]

			outlets for most jobs.
	Liquid-Penetrant Testing		
<i>Fluorescent or dye penetrant, developers, cleaners (solvents and emulsifiers). Suitable cleaning gear. Ultraviolet light source if fluorescent dye is used.</i>	<i>Weld discontinuities open to the surface such as cracks, porosity, lack of fusion.</i>	<i>Can be used on all nonporous materials. Portable, inexpensive equipment gives fast results. Data are easy to interpret. Requires no electrical energy except for ultraviolet light source. Indications can be further examined visually.</i>	<i>Surface films such as coatings and scale will hide rejectable defects. Bleed out from porous surface can mask indications. Parts must be cleaned before and after inspection.</i>
	Eddy-Current Testing		
<i>An instrument capable of introducing electromagnetic fields within a test workpiece and sensing the resulting electrical currents (eddies) induced with a suitable probe or detector. Calibration standards.</i>	<i>Weld discontinuities open to surface such as cracks, porosity, fusion problems, as well as subsurface inclusions. Alloy content, heat-treatment variations, wall thickness.</i>	<i>Fast, low-cost method. Automation possible for symmetrical parts. No coupling fluid needed. Probe does not have to be in intimate contact with test piece.</i>	<i>Limited to conductive materials. Shallow depth of penetration. Indications may be masked by part geometry. Reference standards required.</i>
	Acoustic-Emission Testing		
<i>Emission sensors, amplifying electronics, signal-processing electronics including frequency gates, filters. A suitable output system for evaluating the acoustic signal (audio monitor, visual monitor, counters, tape recorders, X-Y axis recorder).</i>	<i>Internal cracking in welds during cooling, crack initiation, and growth rates.</i>	<i>Real time and continuous surveillance inspection. May be inspected remotely. Portable equipment.</i>	<i>Requires the use of transducers coupled on the test-part surface. Part must be "in-use" stressed. Ductile materials yield low-amplitude emissions. Noise must be filtered out of the inspection system.</i>

Table 4.2: Major Welding Defects and Countermeasures [10]

No.	Kinds of defects	Causes of defects	Countermeasures
1	Undercut	<ol style="list-style-type: none"> 1. Too large welding current is used 2. Welding speed is too fast. 3. Welder is not skilled. 4. Arc is too long. 5. Electrode drag angle is large. 	<ol style="list-style-type: none"> 1. Welding current and speed are lowered to a proper level. 2. An electrode of proper diameter conforming to plate thickness is selected. 3. Arc length is made to the same as electrode diameter. 4. Electrode holding angle is corrected.
2	Overlap	<ol style="list-style-type: none"> 1. Low current, slow welding speed. 2. Arc is too short. 3. Aiming of electrode is not proper. 	<ol style="list-style-type: none"> 1. Obtain correct current and speed. 2. In the case of covered electrode, arc is made longer In the case of CO₂ gas shielded arc welding, arc voltage is raised. 3. Hold electrode in correct angle.
3	Pit	<ol style="list-style-type: none"> 1. Groove is smudged (rust, oil, paint, moisture, etc.) 2. Covered electrode and flux (submerged arc welding) absorbed moisture. 3. Shielding by CO₂ is inadequate. 	<ol style="list-style-type: none"> 1. Groove is cleaned. 2. Covered electrode and flux must be dried. 3. CO₂ is flowed at 20 l/min. when wind velocity is more than 2m/sec. countermeasure for preventing wind should be made. Arc length is shortened.
4	Slag inclusion	<ol style="list-style-type: none"> 1. Welding technique is poor. 2. Electrode diameter is improper. 3. Slag of previous layer bead is not removed completely. 4. Groove is too narrow. 5. Steel plate is tilted downward to welding direction. 	<ol style="list-style-type: none"> 1. Technique must be improved. 2. Proper electrode diameter is to be used. 3. Slag is removed completely. 4. Groove angle widened. 5. Plate is horizontally placed and welding speed is made faster.

(...con't) Table 4.2: Major weld defects and countermeasures

No.	Kinds of defects	Causes of defects	Countermeasures
5	Herringbone	<ol style="list-style-type: none"> 1. Rust, paint, scale adhered to the surface of groove. 2. Flux absorbed moisture. 	<ol style="list-style-type: none"> 1. Groove face is cleaned. 2. Flux is dried.
6	Poor appearance	<ol style="list-style-type: none"> 1. Large or small welding current. 2. Electrode movement is improper. 3. Welding electrode absorbed moisture. 4. Arc is too long (arc voltage is too high). 5. Steel plate is overheated. 	<ol style="list-style-type: none"> 1. Proper current is used. 2. Welding speed and weaving width must be unified. 3. Covered electrode is dried. 4. Proper arc length and voltage must be used. 5. Continuous welding is avoided.
7	Excessive reinforcement	<ol style="list-style-type: none"> 1. Welding speed is too slow. 2. Layers are too many. 3. Electrode is too thick for plate thickness. 4. Arc voltage is low. 	<ol style="list-style-type: none"> 1. Proper welding speed is used. 2. Layers should not be increased. 3. Proper electrode diameter is selected. 4. Arc voltage is raised to a proper value.
8	Crack	<ol style="list-style-type: none"> 1. Embrittlement by hydrogen. 2. Impurities of base metal are too much. 3. Restraint force is large. 	<ol style="list-style-type: none"> 1. Base metal is preheated. 2. Covered electrode of low-hydrogen type is used. CO₂ gas shielded arc welding is used. 3. Steel plate containing much harmful impurities is not used.
9	Incomplete joint penetration	<ol style="list-style-type: none"> 1. Groove is narrow. 2. Welding current is low. 3. Arc voltage is too high. 4. Welding speed is slow in the groove. 5. The aiming position of electrode is not good. 	<ol style="list-style-type: none"> 1. Groove angle is widened. 2. Welding current is raised. 3. Arc voltage is lowered to a proper value. 4. Welding speed is raised. 5. Electrode is aimed at the center of groove.
10	Blowhole	<ol style="list-style-type: none"> 1. Groove is dirty (rust, paint, moisture, oil, etc.). 	<ol style="list-style-type: none"> 1. Groove is cleaned. 2. Welding materials are dried.

(...con't) Table 4.2: Major weld defects and countermeasures

No.	Kinds of defects	Causes of defects	Countermeasures
		<ol style="list-style-type: none"> 2. Covered electrode and flux absorbed moisture. 3. Shielding by CO₂ is inadequate. 4. Large current is used. 5. Weaving width is large. 	<ol style="list-style-type: none"> 3. Flow rate of CO₂ is made 20l/min. when wind velocity is more than 2m/sec. countermeasure for wind should be taken. 4. Proper current is used. 5. Weaving width of covered electrode is less than 3 times the electrode diameter.

CHAPTER FIVE

5. ANALYSIS OF WELD DESIGN & PROCESS OF LOCAL FABRICATED VEHICLE BODIES

5.1. METHODOLOGY

In this chapter analysis on weld design and process of local representative heavy duty vehicle body builders is conducted. The procedure employed to carry out this task is by observing the processes and products of each selected company at their manufacturing workshop and by distributing & analyzing questionnaires.

From close observation of the fabrication processes and evaluation of the companies' response to the questionnaires the basic weld related problems of the companies are identified and subsequently solutions are proposed.

In connection to this specific products of these companies are selected for the above mentioned purpose. The criteria for the selection of the products are set. According to the criteria the standard products of the companies selected are, fuel tanker body, cargo body, dumper body with their mounting frames and low-bed semi-trailer chassis. These products are analyzed with respect to their weld design and processes.

5.2. LOCAL HEAVY DUTY VEHICLE BODY BUILDERS

Four local representative heavy duty vehicle body builders are selected for the purpose of this paper. The selection is based on set criteria. The criteria of selection of the companies are:

- i) Companies ,in the country ,which involve in fabrication of Heavy Duty Vehicle Bodies
- ii) Fabricate significant numbers of Heavy Duty Vehicle Bodies
- iii) Having better installed facilities to carry out fabrication by welding technology
- iv) Relatively well-established fabrication company

According to the criteria the local heavy duty vehicle body builder companies selected for case study are:

- A) Automotive Manufacturing Company of Ethiopia [A.M.C.E]
- B) Maru Metal Industry P.L.C
- C) Mesfin Industrial Engineering Share Company [M.I.E]
- D) Techale General Metal & Wood Works P.L.C

5.3. PRODUCT RANGE OF THE COMPANIES

A) Automotive Manufacturing Company of Ethiopia [A.M.C.E]

Product range

- Assemble heavy duty trucks
- Cargo body mounted on truck
- Cargo body trailer trailed by truck

B) Maru Metal Industry P.L.C

Product range

- Cargo body mounted on truck
- Dumper body assembled on truck
- Fuel and water tankers mounted on trucks
- Low-bed trailers
- Trusses
- Canopies and others

C) Mesfin Industrial Engineering Share Company [M.I.E]

i) Organizational Profile

Site

- Total area.....250,000 m²
- Covered area.....35,000m²

Technical Staff

- Engineers.....32
- Polytechnic.....25
- Vocational school graduates.....195
- Technical school graduates.....132

Support staff

- Administration, finance, supply and others.....78
- Total number of employees.....470

Manufacturing Plants

- Material Preparation plant
- Manufacturing and steel construction plant
- Industrial maintenance and EM erection services plant
- Vehicles maintenance and rental services department

Production Capacity (Annual)

- Dry Cargo body.....2,465
- 3-axle fuel cargo trailer tanker.....2,240
- Fuel cargo tanker.....2,245
- 3-axle dry cargo trailer.....2,240

Production Machineries

- Bending rolls.....1
- Hydraulic shearing machine.....1
- Rolling machine.....1
- Hydraulic press brake.....2
- Dynamic oil squaring shear.....1
- Plasma air cutting machines.....4
- Co-ordinate oxy-acy. cutting machine.....1
- Flame cutting machines with two blow pipes.....3
- Flame chamfering machine.....3
- Heavy duty leveling.....2
- Arc welding machines, 400 AMP, 18 KVA.....70
- MAG welding machines, 450 AMP, 20 KVA.....150

- Super MIG Semi-Automatic welding machines
(500 AMP, 22 KVA).....6
- TIG welding machines, 500 AMP, 22 KVA.....15
- Submerged arc welding machines.....4
(Semi-automatic 100 AMP)
- Sand blasting machines.....9

Machine Tools

- Lathe 1500 mm.....1
- Lathe 3000 mm.....1
- 3-spindle pillar drill.....1
- Circular hydraulic hack saw.....1
- Semi-automatic band saw.....1
- Universal milling.....1

Handling equipment

- Overhead cranes, 10 ton.....4
- Overhead cranes, 5 ton.....8
- Overhead cranes, 3.2 ton.....3
- Mobile crane T.50, T.30, T.20, T.10.....one each
- Forklifts ,5 ton.....5
- Forklifts ,2.5 ton.....2

Testing equipment

- Ultrasonic flow detector.....3
- Radiography/X-ray.....3
- Magnetic particle.....1
- Liquid penetrate.....1

ii) Product range

- Cargo body mounted on truck
- Dumper body assembled on truck
- Fuel and water tankers mounted on trucks
- Low-bed trailers

- Trusses
- The hydroelectric power generation structural components (for instance, penstock, surge tank and so on)

D) Techale General Metal & Wood Works P.L.C

i. Organizational Profile

Site

- Total area.....6000m²
- Covered area..... 2500m²

Technical Staff

- Engineers.....2
- Polytechnic.....5
- Vocational school.....15
- Others.....24

Support staff

- Administration.....8
- Finance.....3
- Supply.....5
- Total.....67

Manufacturing workshops

- Material Preparation Unit
- Vehicle Body Fabrication Unit
- Trailer Production Unit
- Steel Structure Works Unit

Production Capacity (Annual)

- Cargo body.....250
- Tipper body.....25
- Tanker body.....150
- Depots (average 100 m³).....100
- Trailer.....250
- Steel structure.....200 tons

Production Machineries

- Bending machine, 12 mm, 6 m, /16 mm, 6 m.
- Shearing machine, 5 mm, 3 m/ 6 mm, 4 m.
- Rolling machine, 2 m/6 m.
- Hydraulic press
- Punching machine
- Plasma cutting machine
- Arc welding machines
- Spot welding machines
- MAG welding machines

Machine Tools

- Lathe
- Radial drill
- Pedestal drill

Material Handling

- Overhead crane (10 ton)
- Mobile crane (20 ton)
- Pedestal hoist crane (1 ton/3 ton)
- Forklift (5 ton)

ii) Product range

- Cargo body mounted on truck
- Fuel and water tankers mounted on trucks
- Fuel and water tankers trailed by trucks
- Trusses
- Canopies and others

5.4. PRODUCTS SELECTED FOR THE CASE STUDY

Some representative products of the companies are identified to conduct case study on them. These products are identified based on a set of criteria. Criteria for their selection are:

- i.* Significant quantity of fabrication
- ii.* Frequency of their utilization in transportation of cargo
- iii.* Extent of application in the construction industry

According to these criteria the following products are identified to conduct case study on them with respect to their weld design and process.

1. Fuel tanker body and its mounting frame (truck mounted)
2. Cargo body and its mounting frame (truck mounted)
3. Dumper body and its mounting frame
4. Low bed semi trailer chassis

GENERAL CONSTRUCTION OF THE PRODUCTS

5.4.1. FUEL TANKER BODY AND ITS MOUNTING FRAME

This product is composed of three main components, for the sketch refer appendices-XIII.

- i)* Tanker body
- ii)* Mounting frame (false chassis) and
- iii)* Accessories (charging valves, discharging valves, manhole, drainage valve and so on)

i) TANKER BODY

- Material : Mild steel sheet (St.37 to St.52)
- Thickness : 3 mm to 5 mm
- Manufacturing technology : Welding the rolled shell of steel sheet to the two end covers

- Capacity : $10m^3$ to $21m^3$
- Shape : Circular /elliptical- cross section
- Weld joint: Butt and fillet joint
- Welding process : Manual Metal Arc Welding /Submerged Arc Welding
- Test used : Leak proof test
- Weld defect test: visual only

As it is attempted to highlight the fabrication process involved above, the fuel tanker body is a circular or elliptical cross-section shell formed by welding together rolled metal sheet and subsequently welding the two ends cover of the shell with properly reinforced sheet metal. The welds need to be continuous both circumferentially and longitudinally for the purpose of making the tanker water-tight. The fuel tanker is internally reinforced with welded rings to enhance its rigidity. In addition to this buffer is made internally by welding sheet metal to the reinforcing rings.

Since one of the major activities involved in the fabrication of the tanker body is mainly welding, the product reliability and quality depends on the weld.

However, as practically observed at fabrication workshop of the companies and analysis from the questioners the proper weld design and process is not given due considerations. In line with this general problems are observed in the fabrication of the product. Some of the basic problems identified are absence of proper weld size selection, lack of progressive weld quality inspection, lack of adherence to proper safety precaution, proper jigs & fixtures are not utilized and welders are not given appropriate qualification on weld.

The problems identified can be traced back to engineering capacity on weld design and process of the companies. The general recommendations to these problems are indicated in chapter six of this paper. Hence, the recommendations could be tailor-made to the objective conditions of the companies to solve such specific problems they face in their fabrication processes.

ii) MOUNTING FRAME (FALSE CHASSIS)

It is the component used to fix the tanker body on the truck chassis. The load of the tanker body (dead weight and pay load) is transmitted to the truck through this sub-structure. Brackets are welded on this structure to fix the tanker body to the truck chassis.

- Material: Mild steel sheet (St.37 to St.52)
- Thickness: 3 mm to 5 mm
- Manufacturing technology: Welding the bent or folded steel sheet to the required shape. Reinforcing of the structure by ribs
- Weld joint: Butt and fillet joint
- Welding process: Manual Metal Arc Welding /Submerged Arc Welding
- Weld defect test: visual only
- Shape: usually saddle

Since this component is highly loaded its weld joint design should be given due consideration however similar and general problems mentioned in the case of tanker body fabrication are encountered here too. The specific problem which can be mentioned for the fabrication of this component is lack of proper jigs, fixtures, and handling (assembling) procedures to facilitate or simplify the welding steps.

The solutions proposed to these problems are the same as those indicated in tanker body fabrication case. For the specific problem of this component fabrication appropriate jig, fixtures and assembling procedure have to be designed.

iii) ACCESSORIES

Accessories are used for the proper utilization and operation of the tanker. The accessories are mainly used for charging, discharging, relieving pressure, draining, inspection (manhole) and so on. The accessories are connected to the tanker body by weld.

- Material: various standard materials
- Manufacturing technology: Welding proper size of pipes which adapts those standard accessories
- Weld joint: Butt and fillet joint
- Welding process: Manual Metal Arc Welding /Submerged Arc welding
- Weld defect test: visual only

The problem observed concerning the welding of accessories to tanker body is that some of those accessories are different in material composition from that of the tanker body. Proper care is not taken in electrode selection and weld procedure required for different materials welding. Hence as a solution it is highly recommended that proper electrode selection and adherence to welding procedure for different material be practiced.

From the general construction explanation given above the technology widely employed in the fabrication of the tanker body is welding. Hence, it is important to emphasize on proper weld design and process selection for strength, life, quality and the safety of the product.

5.4.2. CARGO BODY AND ITS MOUNTING FRAME

This product is composed of four main components, for the sketch refer appendices-XIV.

- i) Panels
- ii) Platte form
- iii) Mounting frame
- iv) Accessories

i) PANELS

The panels are used to support the lateral load of the cargo. They are the walls forming the loading space (compartment). They are designed either in fixed or detachable form.

- Material: Mild steel sheet (St.37 to St.52)
- Thickness: 2 mm to 4 mm
- Manufacturing technology: welding the corrugated steel sheet with reinforcing items
- Weld joint: butt joint & fillet joint
- Weld process: Manual Metal Arc Welding /Submerged Arc Welding
- Weld defect test: visual only

As briefly explained above this component of the cargo body is fabricated by welding corrugated steel sheet cut to sizes with sealing and reinforcing plates. The problems identified with the fabrication of this component are the interchangeability problem and welding of standard accessories to the panel.

The interchangeability problem occurred due to lack of using appropriate jigs and fixtures in fabrication of panels, specially while locating hinges and latches by welding. The latter problem is related to different material composition of the accessories and the panel material. This problem is similar to the case mentioned in accessories welded to tanker bodies.

The solution proposed to the interchangeability problem is to design and employ appropriate jigs and fixtures for fabricating the panel and locating hinges and latches.

For accessories weld problem the same solution given in section 5.4.1 (iii) can be used.

ii) PLATTE FORM

This component of the cargo body is where the load of cargo is lying. The load of the cargo is distributed over this part. It consists of lateral and cross frames, which is so arranged to evenly support the cargo load.

The cross-frames & the lateral frames are fixed to the mounting frame by welding. The cross frames and the lateral frames are fixed to each other by welding too. The Platte form is covered with checkered plate.

- Material: Mild steel sheet (St.37 to St.52)
- Thickness: 4 mm (min.)
- Manufacturing technology: Welding bent cross frames and lateral frames
- Shape: The lateral frames are usually bend in C-cross section profile and straight. Similarly, the cross frames are bend in C-cross section profile but tapered in longitudinal direction.
- Weld joint: fillet joint & butt joint
- Welding process: Manual Metal Arc Welding / submerged arc welding
- Weld defect test: Visual only

As indicated above this component is carrying the cargo load. Hence the weld joint design must be given special attention. However, in almost all of the companies under the case study, the weld strength design even for such critically loaded component is not carried out. The weld size is determined at workshop floor by the welder from experience. Such practice should be discouraged from engineering points of view, specially, for critically loaded components. Therefore, it is highly recommended that for such components proper welding design standard procedure strictly followed.

The problems identified and solutions proposed in section 5.4.1 (i) still holds for this component.

iii) MOUNTING FRAME

It is the component used to fix the cargo body on the truck chassis. The whole load of the cargo body (dead weight & payload) is transmitted to the truck through this substructure. Brackets are welded on this structure to fix the cargo body to the truck chassis. The mounting frame consists of two lateral frames and a set of cross frames. The cross frames are assembled to the lateral frames by weld. The cross frames and lateral frames are formed from mild steel sheet into C-cross section profile. The transverse shape of the false chassis is geometrically designed to match the shape of the truck chassis.

This is the critically loaded part of the cargo body; the whole load is on it,

- Material: mild steel sheet (St.37 to St.52)
- Thickness: 4 mm to 6 mm
- Manufacturing technology: weld the bent lateral & cross frames
- Shape: both lateral and cross-frames are usually bend into C-cross sectional shape
- Weld joint type: fillet / butt joints
- Welding process: Manual Metal Arc Welding / submerged arc welding
- Weld defect test: Visual only

The problems identified and the corresponding solutions given in section 5.4.2 (ii) hold for this fabrication.

iv) ACCESSORIES

Accessories are used on this product to keep the payload in secured condition. Those accessories are load seal rings, winches, tarpaulins, panel latches and others. They are all fixed on the product by welding.

Concerning their weld related problems and corresponding solution the points in section 5.4.1 (iii) holds.

The cargo body fabrication is mainly carried out by welding. Therefore, it is essential to give due consideration to the proper weld design and process selection for strength, life, quality and the safety of this product.

5.4.3. DUMPER BODY AND ITS MOUNTING FRAME

This product is composed of four main components, for the sketch refer appendices-XV.

- i) Dumper(tipper) body
- ii) Dumping hydraulic system
- iii) Mounting frame
- iv) Accessories

i) DUMPER BODY

The dumper body is constructed from steel sheet by welding. This body is reinforced by ribs. The thickness and the material out of which the body is constructed vary according to the purpose for which it is intended. The rear gate of the body is designed in various ways, for opening and inclination angle. The common mode of dumping is rear tipping.

- Material: Mild steel sheet (St.37 to St.52)
- Thickness: 4 mm(min.)
- Manufacturing technology: welding bent steel sheet/plate and reinforcing with reinforcing items
- Weld joint: butt joint & fillet joint
- Weld process: Manual Metal Arc Welding /Submerged Arc Welding
- Weld defect test: visual only

Same problems and corresponding solutions in section 5.4.1 (i) hold for this case.

ii) DUMPING HYDRAULIC SYSTEM

This is standard hydraulic system fitted into the body for actuating the dumper body. There are various standards of hydraulic rams that are selected according

to the load and dumping specification. For the fitting purpose these component is provided with appropriate fitting provisions from the manufacturer. The stages of the ram range from two to four. The hydraulic system actuation is commonly performed from the inside of driver's cabin.

iii) **MOUNTING FRAME**

It is the component used to support the dumper body and the pay load and thereby transfer the load to the truck chassis. The load of the dumper (dead weight and payload) is transmitted to the truck chassis through this sub-structure. This mounting frame consists of two lateral frames and a set of cross frames. The cross frames are assembled to the two lateral frames by welding. The cross frames and lateral frames are formed from mild steel sheet into C-cross section profile. The transverse shape of the mounting frame is geometrically designed to match the shape of the truck chassis. Brackets are used to fix the mounting frame to the truck chassis.

- Material: Mild steel sheet (St.37 to St.52)
- Thickness: 4 mm to 6 mm
- Manufacturing technology: welding the bent lateral and cross frames
- Shape: lateral and cross-frames are usually bent into C-cross section
- Weld joint: butt joint & fillet joint
- Weld process: Manual Metal Arc Welding /Submerged Arc Welding
- Weld defect test [DT or NDT] : visual only

Same problems and corresponding solutions in section 5.4.2 (ii) hold for this case.

iv) **ACCESSORIES**

Accessories are used on this product for its proper operation. The accessories are rear gate automatic locks, spare wheel holder and others. They are fixed on the product mainly by welding.

Concerning their weld related problems and corresponding solution the points in section 5.4.1 (iii) holds.

The dumper body fabrication is mainly carried out by welding. Hence, it is essential to give due consideration to the proper weld design and process selection for strength, life, quality and the safety of this product.

5.4.4. LOW BED SEMI TRAILER CHASSIS

This product is composed of four main components, for the sketch refer appendices-XVI.

- i) Chassis frame
- ii) Platte form
- iii) Ramp
- iv) Fifth wheel coupling and accessories

i) CHASSIS FRAME

This component is fabricated from two lateral frames and set of cross sections welded together. The lateral frames are I-sections, which are either standard (rolled) or fabricated from flanges and webs by welding. The cross frames are C-cross sectional elements or I-cross sectional elements. Low bed semi-trailers are usually used to mobilize earth moving machineries like bull dozer, grader, excavator, and so on. These equipments are very heavy in weight. The chassis of low bed semi trailers are designed to support such extremely heavy weight equipment. The weld joint design and material has to be given due attention to enable support such very heavy load.

- Material: Medium carbon (St.37 to St.52)
- Thickness: 10 mm to 25 mm
- Manufacturing technology: welding the lateral frame with set of cross frames
- Shape: lateral and cross-frames are I-sections
- Weld joint: butt joint & fillet joint

- Weld process: Manual Metal Arc Welding /Submerged Arc Welding
- Weld defect test [DT or NDT] : visual only

Concerning this component the lateral frame weld should be given due attention because this component is long and thick, therefore if not properly restrain it is liable to distortion. Properly designed clamping jigs and fixtures and careful welding sequence must be used.

ii) **PLATTE FORM**

This component of the low bed semi trailer is where the load (equipment) is loaded or placed. The weight of the equipment is distributed over this Platte form. It consists of lateral and cross frames, which are so designed that to evenly support the equipment load. The cross frames and the lateral frames are fixed to the chassis frame by welding. There are extension brackets on Platte form widthwise to increase the width of the Platte form to support wider equipments. The extending brackets are hinged to the Platte form.

- Material: Medium carbon (St.37 to St.52)
- Thickness: 6 mm to 10 mm
- Manufacturing technology: welding the lateral frame with set of cross frames
- Shape: lateral frames are I-sections while cross-frames are C-sections
- Weld joint: butt joint & fillet joint
- Weld process: Manual Metal Arc Welding /Submerged Arc Welding
- Weld defect test [DT or NDT] : visual only

iii) **RAMP**

This is the part of low bed semi trailer which enables to ramp up and down equipment loaded on the trailer. The ramps are hinged on the trailer at rear. They are lowered to the ground level when loading and unloading is arranged, otherwise folded up. On a trailer there are two ramps (left and right). The ramp is constructed from lateral frames and set of cross frames. The lateral frames are

usually I-sections while the cross frames are C-sections. The lateral frames and cross frames are assembled by welding. The ramps are covered by checkered plate to enable traction for loading equipment.

- Material: Medium carbon (St.37 to St.52)
- Thickness: 6 mm to 10 mm
- Manufacturing technology: welding the lateral frame with cross frames
- Shape: lateral frames are I-sections while cross-frames are C-sections
- Weld joint: butt joint & fillet joint
- Weld process: Manual Metal Arc Welding /Submerged Arc Welding
- Weld defect test [DT or NDT] : (visual only)

iv) **FIFTH WHEEL COUPLING AND ACCESSORIES**

The fifth wheel coupling is a standard component that is used to couple the low bed semi-trailer with the truck tractor. The weight of the load is transferred to the truck tractor through the fifth wheel coupling. For the fitting purpose there is provision on the standard coupling from manufacturer.

Accessories are used for properly securing the load in place. Those accessories are heavy duty winch, loading winch (motorized), spare tire holder and others. Most of those accessories are welded to the trailer.

5.5 SAMPLE OF WELD STRENGTH ANALYSIS

To indicate the weld strength analysis procedure for a trailer critically loaded component, external cross member, is taken. The detail of analysis is shown below:

5.5.1 STRENGTH ANALYSIS

Assumptions:-

1) Loading

Assuming that the load of the cargo is transmitted from the chequered plate to the cross member through the longitudinal beams and side beams. So

$R_1=959.39\text{N}$ and $R_2=2689.4\text{N}$ are the loads due to the cargo distributed through side beam and longitudinal beam respectively. But there is additional weight of the side beam and the longitudinal side omega -(15 in number) which are to be loaded on the external cross member.

$$R_1 = 959.39 + \frac{78.2 \times 9.81}{15} = 1010.5\text{N}$$

$$R_2 = 2689.4 + \frac{50 \times 9.81}{15} = 2722\text{N}$$

2) Support

The cross member can be considered as a cantilever beam as shown in the figure below

Since the cross section of the cross member vary along its length, let's check the safety factor at three different points as shown in the figure below.

Case 1 (front external cross member)

.

Case 2 (rear external cross member)

.

For the above different points the result for direct shear force, induced bending stress, shear stress, maximum shear stress and factor of safety is as shown in the table below.

The cross member is made of St-42 having yield strength of 255 MPa.

$$\Rightarrow \tau_y = 0.5\sigma_y = 0.5 \times 255 \text{ MPa} = 127.5 \text{ MPa}$$

Part	Option	Bending moment (N/m)	Induced bending stress (MPa)	Shear force (N)	Induced shear stress (MPa)	Combined Max. shear stress (MPa)	Shear yield stress (MPa)	Safety factor (static)
Front ext. cross member	1	259.7	7.16	1010.5	0.86	3.68	127.5	34.63
	2	850.1	19.77	3732.5	3.02	10.33	127.5	12.34
	3	1846.7	36.90	3732.5	2.87	18.67	127.5	6.83
Rear ext. cross member	1	259.7	6.13	1010.5	0.82	3.17	127.5	40.17
	2	850.1	15.60	3732.5	2.78	8.28	127.5	15.40
	3	1846.7	26.94	3732.5	2.55	13.71	127.5	9.30

5.5.2 WELDING ANALYSIS

As can be seen from above the maximum bending moment and direct shear force are occurred at the end of the cross members and because those loads are totally carried by the welding, it is necessary to check the weld size.

Currently the cross member is welded with the chassis as shown in the figure below.

Case 1(front external cross member) Case 2 (rear external cross member)

• •

Case 1

Let h be throat size of the weld and a weld size.

Then, $h=0.707a$

It is known that failure of the weld occurs due to the shearing along the throat section when the weld is bending.

Area of the weld group

$$A = 2 \times 0.108h + 3 \times 0.075h = 0.441h$$

Distance of center of gravity of the weld group at the top part is

For the L-shape

$$y = \frac{0.118 \times a \times 0.059}{0.080 \times a + 0.108 \times a} = 0.0352m$$

For the C-shape

$$y=0.059 \text{ m}$$

Totally for the group

$$y = \frac{0.258 \times a \times 0.059 + 0.198 \times a \times 0.0352}{0.258 \times a + 0.198 \times a} = 0.04867m$$

And moment of inertia of the weld group is

$$I_{xx} = \left(\frac{(6.0 \times 0.075 + 0.108^3) \times 0.118^4}{12 \times (0.118 + 0.08)} h + (0.08 + 0.118)h \times 0.01347^2 \right)$$

$$= 908.71 \times 10^{-6} hm^4$$

So the bending stress at the extreme top is

$$\sigma = \frac{My}{I_{xx}} = \frac{1846.7 \times 0.04867}{908.71 \times 10^{-6} h} = \frac{0.0989}{h} MPa$$

And the bending stress at the extreme bottom is

$$\sigma = \frac{My}{I_{xx}} = \frac{1846.7 \times (0.118 - 0.04867)}{908.71 \times 10^{-6} h} = \frac{0.14089}{h} MPa$$

And direct shearing stress due the distributed load is

$$F_{sh} = 1010.5N + 2722N = 3732.5N$$

$$\tau = \frac{F_{sh}}{A} = \frac{3732.5}{0.441h} = \frac{0.008464}{h} MPa$$

Therefore, according to maximum shear stress theory, taking the maximum bending stress in to consideration

$$\tau = \sqrt{\tau_{ind}^2 + \left(\frac{\sigma_{ind}}{2}\right)^2} = \frac{0.07095}{h} MPa$$

Assuming factor of safety to be 5, the allowable shear stress becomes, note in this case property of the welding wire for **EN440 G3Si-1** is $\sigma_y = 475MPa$

(Reference: ESAB welding handbook)

$$\tau_{all} = \frac{\tau_y}{F.S} = \frac{0.5 \times 475MPa}{5} = \frac{0.07095}{h} MPa$$

Therefore, since

$$\tau_{max} \leq \tau_{all} \Rightarrow \frac{0.07095}{h} \leq 47.5 \Rightarrow h \geq 0.001494m$$

And the welding size will be

$$a = \frac{h}{0.707} = \frac{0.001494}{0.707} = 0.002113m$$

Assuming the welding efficiency to be 50%, the actual welding size becomes

$$a_{actual} = \frac{a}{0.5} = \frac{0.002113}{0.5} = 0.004226m \Rightarrow a_{actual} = 5mm$$

Case 2

For this case

$$A = 0.15h + 0.14h + 2 \times 0.075h + 0.08h = 0.52h$$

Distance of center of gravity of the weld group of the horizontal fillet

For the L-shape

$$y = 0.150 - \frac{0.150^2}{2(0.08 + 0.150)} = 0.101m$$

For the C-shape

$$y = 0.075m$$

Totally for the group

$$y = \frac{0.29 \times a \times 0.075 + 0.23 \times a \times 0.1011}{0.29 \times a + 0.23 \times a} = 0.08654m$$

And the moment of inertia of the weld group is

$$I_{xx} = \left(\frac{(6.0 \times 0.075 + 0.14) \times 0.14^2}{12} h + (2 \times 0.075 + 0.14) h \times 0.01154^2 \right) + \left(\frac{4 \times 0.08 \times 0.15^3 + 0.15^4}{12 \times (0.15 + 0.08)} h + (0.08 + 0.15) h \times 0.01456^2 \right)$$

$$= 1.626 \times 10^{-3} h m^4$$

So the bending stress at the extreme top

$$\sigma = \frac{My}{I_{xx}} = \frac{1846.7 \times 0.08654}{1.626 \times 10^{-3} h} = \frac{0.0983}{h} MPa$$

And direct shearing stress due the distributed loads is

$$F_{sh} = 1010.5 + 2722 = 3732.5 N$$

$$\tau = \frac{F_{sh}}{A} = \frac{3732.5}{0.52h} = \frac{0.007177}{h} MPa$$

Therefore according to maximum shear stress theory

$$\tau_{max} = \sqrt{\tau_{ind}^2 + \left(\frac{\sigma_{ind}}{2} \right)^2} = \frac{0.04967}{h} MPa$$

Assuming factor of safety 5, the allowable shear stress becomes

$$\tau_{all} = \frac{\tau_y}{F.S} = \frac{0.5 \times 475 MPa}{5} = 47.5 MPa$$

Therefore, since

$$\tau_{max} \leq \tau_{all} \Rightarrow \frac{0.04967}{h} \leq 47.5 \Rightarrow h \geq 0.0010457 m$$

And the welding size will be

$$a = \frac{h}{0.707} = \frac{0.0010457}{0.707} = 0.001479 m$$

Assuming the welding efficiency to be 50%, the actual welding size becomes

$$a_{actual} = \frac{a}{0.5} = \frac{0.001479}{0.5} = 0.002958 m \Rightarrow a_{actual} = 3 mm$$

Table 5.1: Questionnaires Analysis

S.No.	Questioners	Companies response			
		A.M.C.E	MARU	M.I.E	TECHALE
1	Organizational profile	Not Attached	Not Attached	Attached	Attached
2	Weld design				
2.1	For the fabrications you carry out, do you have weld design?	Train welder on what procedures to follow, one of the procedures is weld design, what a welder should do before starting the weld.	It depends on the criticalness of the design. Otherwise, use the common welding size	Weld design is performed on some critical items, such as cross members for platform of a trailer	Weld design is not conducted for any of their fabrication. Weld fabrication is carried out by experience.
2.2	How do you determine the weld sizes, specially, on critically loaded components?	Weld size is determined with thickness of material that is going to be joined. For sizes normally the standard practice is followed	Design it against shearing.	First the part is modeled (Geometry, loading condition, constraints), then calculate the stresses on the weld joint. Finally compare the stress with strength of weld material to determine the safety factor	Simply selected from ESAB weld electrode manual.
2.3	How do you select the electrode (filler) material (its type)?	The selection of electrode is done by comparing the material used to produce the electrodes with that of the material to be welded; they need to have the same characteristic in all aspects.	By experience	Quality of material (base metal), thickness of base metal, required depth of penetration, productivity and welding position	Simply selected from ESAB weld electrode manual.
2.4	How do you select the electrode size?	Use the standards and practices used by the companies producing welding electrodes.	Depends on the thickness of the plate to be welded	Based on base metal thickness	Simply selected from ESAB weld electrode manual.
2.5	Is there any standard code you adapt for your weld design (fabrication)?	There is no any standard code adapted or used. Follow normal practice of	Not specified.	AWS-standard and ESAB welding handbook	No specific weld design standard or code is adapted.

Table 5.1: Questionnaires Analysis

S.No.	Questioners	Companies response			
		A.M.C.E	MARU	M.I.E	TECHALE
		welding system.			
2.6	How do you match the parent metal material with filler material?	Refer to the standards given by the producers of electrode to match the required filler material.	Not specified.	By referring to ESAB welding handbook	Simply selected from ESAB weld electrode manual.
2.7	What type of material do you use for your main product fabrication?	St-37, St-42 and St-52	St-37, St-42 and St-52	St-37, St-42 and St-52	St-37, St-42 and St-52
3	Welding process				
3.1	What welding processes do you use?	Use conventional metal shielded arc welding and gas shielded metal arc welding CO2 shielded. Wire welding is utilized.	Arc welding, MAG welding, submerged arc welding (for petroleum depots)	Arc welding, MAG welding, submerged arc welding (for petroleum depots)	Manual metal arc welding is used. Recently MIG is being introduced.
3.2	How did you select this process?	Based on the type of material and thickness.	Not specified	Based on purpose (required strength), base material (quality & thickness), productivity (economy or cost of manufacturing)	Based on type of production and economic factors
3.3	What is the disadvantage and advantage of this welding process over others known?	Advantage: no slag, clean finish, better penetration, less heat affected zone. Disadvantage: need skilled welders, defects can not easily be detected.	Not specified.	Not specified.	Not explained
3.4	How do you analyze the effect of this welding process on the quality of your product?	Not specified.	Not specified.	Some specific items are selected as per the required quality of weld (arc or MAG). In the opinion of MIE the weld quality is rated as good	

Table 5.1: Questionnaires Analysis

S.No.	Questioners	Companies response			
		A.M.C.E	MARU	M.I.E	TECHALE
4	Weldment preparation				
4.1	What is the range of the thickness of metal you employ in the welding fabrication? [Min. to max.]	Steel material ranging 0.6 mm to 10 mm.	Steel material ranging 0.75 mm to 50 mm.	Steel material ranging 2 mm to 25 mm.	Steel material ranging 2 mm to 8 mm.
4.2	Is there any standard you adapt to carry out material preparation for welding?	No	No	Yes, ISO 5817:1992(E), MIE GWQAL 002/06 (General Welding Quality Acceptance level)	No specific standard is adapted. But groove is made for high penetration weld.
4.3	What devices do you employ to make material preparation for welding?	Normally weld material thickness up to 8 mm. For small thickness weld with out any preparation. But for bigger thickness prepare V or U-type groove with grinding machine. Keeping standard parameters.	Not specified	Chamfering machine for edge preparation/jigs and fixtures	Not specified.
5	Weld quality				
5.1	What measures do you take to avoid the formation of weld porosity?	Clean the material before welding; adjust the speed for wire & current.	Weld in confined area where there is no wind.	Adjustment of welding parameters like current, speed rate of welding	By proper selection of voltage and current. Keeping neat the surface of parent material.
5.2	What measures do you take to avoid the slag inclusion?	As much as possible avoid air contact to the welding material while welding & use the standard current range and wire speed.	Weld with proper current	Removing (cleaning) the slag inclusions before proceeding to next process	Properly removing the slag before proceeding to the next pass (if it is multi-pass weld).
5.3	What measures do you take to avoid weld distortions?	For small thickness, cool the heat affected zone by applying water. And for larger thickness restrain the weldment & leave it	Clamp the workpiece in place, limit the amount of heat input, welding sequence used should not be from one end	Use proper welding procedure. Check jigs and fixtures which are used for some items.	Use proper welding sequence. Employ jigs and fixtures where necessary.

Table 5.1: Questionnaires Analysis

S.No.	Questioners	Companies response			
		A.M.C.E	MARU	M.I.E	TECHALE
		until it gets cool.	directly to the other, but staggered.		
5.4	What are the frequent welding related problems observed in your fabrication process? What measures did you take to remedy them?	Apply load against the defected area.	Not specified	Trailer suspension support weld cracking.	Not specified.
5.5	How do you keep welding electrodes, specially, if it is flux shielded one?	In dry place.	In dry place.	In dry place.	In dry place.
6	Testing and inspection				
6.1	Do you carry out any welding test on your weld? If so what sort of testing?	Only visual inspection	Not specified	Yes. The tests are: Non Destructive Test [NDT]- (a)X-ray test (b)Ultrasonic test (c)Magnetic particle test (d) Liquid penetrant (e) Vacuum test for reservoir fuel tanker (f) Water test for fuel tankers	Only visual inspection
6.2	How do you carry out the quality control on your weld fabrication products?	By visual inspection; if not satisfied grind and weld again.	By assigning foreman to follow up each welding process.	By dividing the activities of quality control into three main procedures. Namely, incoming inspection, in process inspection and final inspection and additionally quality cost analysis and control of non conformity.	By assigning foreman to follow up each welding process.
6.3	Is there any standard you adapt for weld testing and inspection? If so explain.	No any standard inspection.	Not specified	Not specified	No any standard inspection.

Table 5.1: Questionnaires Analysis

S.No.	Questioners	Companies response			
		A.M.C.E	MARU	M.I.E	TECHALE
7	Codes and standards				
7.1	Is there any welding code you adapt to carry out your welding fabrication? If so mention it.	No any code is used.	Not specified	ISO 5817: 1992(E)	
7.2	If you have not adapted any weld code yet, what is your possible reason?	Not specified	Not specified	-	Not specified
7.3	What is the impact of not adapting any welding code on your product? if any	No specified	Not specified	-	Not specified
7.4	Do you have information on the welding codes available in line of your weld fabrication?	Yes, but not implemented	Yes, but not implemented	Yes	Yes, but not implemented
8	Welder qualification and certification				
8.1	What is the range of qualification of your welders?	They range from assistant welder to Welder-III	They range from assistant welder to Welder-III	They range from welder-I to Welder-III	Vocational school graduates trained on job
8.2	Are your welders certified on a specific welding?	Not specified.	Not specified.	Few welders are certified based on the international standard requirements. But most welders are not certified.	None of the welders are certified.
8.3	If any of your welder is not certified what is its impact on welding fabrication?	Improper welding size and bad weld quality.	Improper welding size and bad weld quality.	(a) It has impact on quality of welding, (b) Difficult to enter to international bid, (c) Impact on the image of the company	Not specified.
9	Weld crack [internal and external]				
9.1	Have you any feed back on weld crack of your welding fabrication product?	Yes, reinforced the cracked part and re-weld the part again	Not specified.	Weld crack at suspension cover plate with longitudinal lower	Not specified.

Table 5.1: Questionnaires Analysis

S.No.	Questioners	Companies response			
		A.M.C.E	MARU	M.I.E	TECHALE
				plate.	
9.2	Have you analyzed the possible cause of the crack? If so mention it.	It is due to improper shield or interference of air and quality of welder to fulfill the requirement.	Not specified.	(a) Different material quality of suspension, cover plate and lower plate (b) Poor welding quality (c) Road condition and vibration (d) Cover plate levelness problem	Not specified.
9.3	What are the measures you take to avoid internal and external weld cracks?	Not specified	Not specified.	The trailers which have a problem of suspension weld crack are rectified, i.e their levelness problem is corrected.	Not specified.

5.6 Summary of evaluation of the companies weld design & process

The result of evaluation of data in table 5.1 above is explained below for each of the companies.

Automotive Manufacturing Company of Ethiopia [A.M.C.E]

As it can be seen from the evaluation table this company has the following problems in its weld design and process:

- There is no well established weld design for its any fabrication process.
- No any standard is adapted or used to perform weld design.
- There is no clearly defined weld process selection procedure the company have adapted or used.
- No standard is adapted or used for weldment preparation
- The steps and measures taken to keep the quality of their weld is not adequate.
- There is no corresponding weld quality inspection section in the company
- There is no any standard adapted or used by the company for its weld quality inspection
- There is no any welding code adapted or used by the company.
- There is no established standard level for welders qualification
- None of the welders are certified on any specific weld process

Maru Metal Industry P.L.C

As it can be seen from the evaluation table this company has the following problems in its weld design and process:

- There is no well established weld design for its any fabrication process.
- No any standard is adapted or used to perform weld design.
- There is no clearly defined weld process selection procedure the company have adapted or used.
- No standard is adapted or used for weldment preparation

- The steps and measures taken to keep the quality of their weld is not adequate.
- There is no corresponding weld quality inspection section in the company
- There is no standard adapted or used by the company for its weld quality inspection
- There is no welding code adapted or used by the company.
- There is no established standard level for welders qualification
- None of the welders are certified on any specific weld process

Mesfin Industrial Engineering Share Company

As it can be seen from the evaluation table this company has the following problems in its weld design and process:

- There is a good start to practice weld design for its fabrication process but not adequate.
- There is a start to adhere to a standard to perform weld design but not well developed.
- There is no clearly defined weld process selection procedure the company have adapted or used.
- There is a good start in establishing standard level for welders' qualification but not adequate-it is limited to international contracts.
- Some of welders are certified on specific weld processes but not adequate it is limited to international contracts.

Techale General Metal and Wood Works P.L.C

As it can be seen from the evaluation table this company has the following problems in its weld design and process:

- There is no well established weld design for its any fabrication process.
- No any standard is adapted or used to perform weld design.
- There is no clearly defined weld process selection procedure the company have adapted or used.

- No standard is adapted or used for weldment preparation
- The steps and measures taken to keep the quality of their weld is not adequate.
- There is no corresponding weld quality inspection section in the company
- There is no standard adapted or used by the company for its weld quality inspection
- There is no welding code adapted or used by the company.
- There is no established standard level for welders qualification
- None of the welders are certified on any specific weld process

5.7 DISCUSSION

Based on the analysis of weld design and process made on the local representative heavy duty vehicles body builders the following discussion could be made which is the ground to generate ideas for the solution proposal.

WELD DESIGN

As it could be seen from the analysis concerning the weld design the local body builders are not on the right track. Except one of the local body builders the rest of the companies, on which the case study is conducted, did not introduce or adapt weld design practice for their fabrication process. One of the body builder companies which attempts to introduce or adapt weld design is currently in the preparation for attaining ISO 9000 certification.

All of the body builders companies do not have weld design manual for their fabrication.

The absence of weld design in most of the local heavy duty vehicle body builders has detrimental effect on the development of the industry in our country. This effect can be explained as follows:

1. All the benefits obtained from adhering to design engineering drawing for fabrication will be lacked.
2. Difficulty of competing for international market.
3. Production quality improvement is difficult

4. The production of the company fully depends on the availability and skill of the individual welders than being on documented data.
5. The economic and proper use of materials is not forecasted scientifically.

WELD PROCESS

The local vehicle body builders' commonly use the manual metal arc welding process. For specific vehicle body components some of the body builders employ submerged arc and MIG/MAG welding processes. All of the companies, on which the case study is conducted, do not have clearly defined selection criteria of the welding process. The proper selection of welding processes plays essential role in productivity and quality of fabrication.

WELD INSPECTION AND TEST

As it is explained in chapter five of this paper welds inspection and testing is very important so as to indicate the quality, strength and properties of the joint being made. Most of the companies, on which the case study is conducted, this task is limited to visual inspection of the weld and leakage test of fuel and water tankers. All of the companies, on which the case studies is conducted, except one do not have a well established quality control department.

One of the four companies have well established quality control department, it has all non destructive test facilities, namely, radiography, ultrasonic, magnetic flux particle and liquid penetrant test. In addition to this the company has weld test safety devices, dose meter and dose meter badge, which warns the person engaged on operation of radiograph against excessive exposure of X-ray.

WELDER QUALIFICATION AND CERTIFICATION

Among the factors that determine the quality of a weld is the skill of the welder. As it is observed from the case studies, most of the welders do not have the basic welding practice training they simply engage in welding operation without acquiring proper welding skill.

From the case studies conducted only one of the companies get some of its welders certified on specific welding. This company has got its welders certified to undertake international contracts. The brief of the certification detail is shown below:

Number & Qualification of Certified Welders

1. Certifying Institute	ISCOR, South Africa
a. Welding process	111(SMAW)
b. Welding position	PF, PC, PA
c. Welding Standard	AWS D1-1-96
d. No. of certified welders	21
2. Certifying Institute	Zavod Za Zavarivanje Yugoslavia
a. Welding process	111(SMAW), 135(MAG)
b. Welding position	PF, PC, PA
c. Welding Standard	EN 287-1
d. No. of certified welders	75
3. Certifying Institute	SLV, Germany
a. Welding process	141(SMAW)
b. Welding position	PF, PC, PA
c. Welding Standard	EN 287-1
d. No. of certified welders	15

WELDING CODE AND SPECIFICATION

As it is explained in this paper welds are designed and executed in accordance with codes, standards, and specifications intended to enhance the integrity of the product and its safe performance in use.

From the case study conducted almost none of the companies adhere to or adapt any of the codes, standards and specifications. Only one of the companies which is on process of attaining ISO 9000 certification is attempting to adapt AWS codes, standards and specification.

In Ethiopia there is no governmental institution or professional societies that have written codes for weld.

MATERIAL

The base material commonly used for the fabrication in the case study companies is mild steel, specifically, St-37, St-42 and St-52. The weld material, electrode and filler, is selected from ESAB weld hand book based on the base material.

As it can be seen from the analysis attempted to make on each company their problem are of common nature. Therefore, as countermeasure recommendations are made in chapter six of this paper as a solution to these problems.

5.8 GENERAL PROBLEMS IDENTIFIED

From the analysis and discussions made above the following weld related general problems of the companies on which the case study is conducted are identified.

1. Though significant numbers of heavy duty vehicle bodies are being fabricated by local vehicle body builders, their engineering weld design is not given appropriate attention. There is no weld design manual in the companies.
2. The welding process selection is done arbitrarily, it is not based on a clearly defined selection criteria.
3. The welding quality inspection and testing is limited to visual inspection, no appropriate corresponding quality control department is established.
4. The welders qualification and wherever necessary welders certification is not given due consideration.
5. Appropriate weld codes, standards and specifications are not well adapted by the body builders.

CHAPTER SIX

6. CONCLUSIONS AND FUTURE WORK OUTLOOK

6.1 CONCLUSION

From the analysis and discussions on the weld design and process in this paper the following conclusions could be made.

1. Proper engineering weld design should be performed specially on critically loaded components, like chassis central lateral & cross frame weld joint. . For this purpose weld design manual has to be developed.
2. It is high time to establish welders qualifying and certifying institute in national level as there is no one yet.
3. It is highly recommendable to the local body builders to establish quality control section that corresponds to their fabrication capacity.
4. In national level Weld Codes, Standards and Specifications are to be written or adapted by responsible government institutes or professional associations like, Ethiopian Society of Mechanical Engineers.
5. It is essential to establish weld testing center which has dual purposes, in the first place render weld testing service and in the second place provide training on weld testing.

6.2 FUTURE WORK

The vehicle body building industry of our country is in need of high engineering inputs. One of the areas of future work could be the effect of road condition on the weld of vehicle body, fracture analysis of weld crack in vehicle bodies and the like.

APPENDICES

APPENDICES-I

CODES AND SPECIFICATIONS FOR WELDS

Welds are designed and executed in accordance with codes, standards, and specifications intended to enhance the integrity of the product and its safe performance in use. Codes and specifications are generally written by industrial groups, trade or professional organizations, or government bureaus, and each code or specification deals with applications pertaining specifically to the interest of the authoring body. Large manufacturing organizations may prepare their own specifications to meet their specific needs.

The American Welding Society (AWS), the American Institute of Steel Construction (AISC), the American Society for Testing Materials (ASTM), the American Society of Mechanical Engineers (ASME), and the American Petroleum Institute (API) are among the major organizations that write codes that involve arc welding.

Among the American government agencies, the Interstate Commerce Commission (ICC) has rules for the fabrication of over-the-road vehicles and for containers used in interstate commerce. The various branches of the military services also prepare specifications—for example, those of the Society of Automotive Engineers (SAE)—actually are not standards, but are merely guides to recommended practices. Other specifications rigidly call out the design and fabrication procedures to be followed and are legally binding. In any event, neither the design nor the fabrication of a welded structure should be undertaken without full knowledge of all codes and requirements that must be met.

Meeting the requirements of a code does not protect anyone against liability concerning the performance of the welds or structure. Nor, in general, does any code writing body approve, endorse, guarantee, or in any way attest to the correctness of the procedures, designs, or materials selected for code application.

The strength values permitted by governing codes are called allowable. Thus there are specified allowable for shear stress and unit forces on various sizes of fillet welds, and there are fatigue allowable for various welds in reference to the geometry of the joint. Most weldments used in machinery are made in accordance with AWS and AISC specifications, with ASME and API rules applicable where pressure vessels and piping are involved.

Allowable Shear and Unit Forces

The basic formula for allowable shear stress τ for weld metal in a fillet or partial penetration bevel groove weld has been established by the AWS and AISC as

$$\tau = 0.30 \times S_t$$

where S_t = minimum tensile strength. Table (I. a) shows the values for various weld metal strength levels obtained by this formula and the more common fillet-weld sizes. These values are for equal-leg fillet welds where the effective throat $t_e = 0.707 \omega$, where ω is the leg size. With table (I. a) one can calculate the allowable unit force f per lineal inch for a weld size made with a particular electrode type. For example, calculating the allowable unit force f per inch for a $\frac{1}{2}$ -in fillet weld made with an E70 electrode gives

$$\begin{aligned} f &= 0.707 \times \omega \times \tau = 0.707 \times \omega \times \tau (0.30 S_t) \\ &= 0.707 (1/2) (0.30) (70) (10)^3 \\ &= 7420 \text{ lb} - \text{per} - \text{linear} - \text{inch} \end{aligned}$$

An AISC provision gives limited credit for penetration beyond the root of a fillet weld made with the submerged-arc process. Since penetration increases the effective throat thickness of the weld increases in this value when calculating weld strength. For fillet welds $\frac{3}{8}$ in. and smaller, the effective throat t_e is now equal to the leg size of the weld ω . Thus

$$t_e = \omega \quad \omega \leq \frac{3}{8} \text{ in}$$

For submerged arc fillet welds larger than $\frac{3}{8}$ in. the effective throat of the weld is obtained by adding 0.11 to 0.707ω . Thus

$$t_e = 0.707 \omega + 0.11 \quad \omega > \frac{3}{8} \text{ in.}$$

Table I.a: Allowable unit loads for various sizes of fillet welds

Tensile strength of weld metal, kpsi						
S_t	60	70	80	90	100	110
Allowable shear stress on throat of fillet weld or partial-penetration groove weld, kpsi						
τ	18.0	21.0	24.0	27.0	30.0	33.0
Allowable unit force on fillet weld, kip/linear in.						
f	12.73	14.85	16.97	19.09	21.21	23.33
Leg size ω , (in.)	Allowable unit force for various sizes of fillet welds, kip/linear in.					
1	12.73	14.85	16.97	19.09	21.21	23.33
7/8	11.14	12.99	14.85	16.70	18.57	20.41
3/4	9.55	11.14	12.73	14.32	15.92	17.50
5/8	7.96	9.28	10.61	11.93	13.27	14.58
1/2	6.37	7.42	8.48	9.54	10.61	11.67
7/16	5.57	6.50	7.42	8.35	9.28	10.21
3/8	4.77	5.57	6.36	7.16	7.95	8.75
5/16	3.98	4.64	5.30	5.97	6.63	7.29
1/4	3.18	3.71	4.24	4.77	5.30	5.83
3/16	2.39	2.78	3.18	3.58	3.98	4.38
1/8	1.59	1.86	2.12	2.39	2.65	2.92
1/16	0.795	0.930	1.06	1.19	1.33	1.46

Note that allowance for penetration applies only to fillet welds made by the submerged arc welding process. Electrode polarity will provide this penetration.

Minimum Fillet Weld Size

The minimum sizes of fillet welds for specific material thicknesses are shown in table (I. b) In the AISC Specifications and the AWS Structural Welding Code; this table has been expanded to include material less than 1/4 in thick and 1/8 in fillets. Where materials of different thicknesses are being joined, the minimum fillet weld size is governed by the thicker material, but this size does not have to exceed the thickness of the thinner material unless required by the calculated stress.

Table I.b: Minimum Fillet-Weld Size w in inches.

No.	Material thickness of thicker part joined	Minimum fillet size
1	To $\frac{1}{4}$ inclusive	$\frac{1}{8}$
2	Over $\frac{1}{4}$ to $\frac{1}{2}$	$\frac{3}{16}$
3	Over $\frac{1}{2}$ to $\frac{3}{4}$	$\frac{1}{4}$
4	Over $\frac{3}{4}$ to $1\frac{1}{2}$	$\frac{5}{16}$
5	Over $1\frac{1}{2}$ to $1\frac{3}{4}$	$\frac{3}{8}$
6	Over $2\frac{1}{4}$ to 6	$\frac{1}{2}$
7	Over 6	$\frac{5}{8}$

Allowable for weld metal-A handy reference

Table (I. c) summarizes the AWS structural welding code and AISC allowable for weld metal. It is intended to provide a ready reference for picking the proper strength levels for the various types of steels. Once this selection has been made, the allowable can be quickly found for the various types of welds that may be required for the specific assembly.

AISC fatigue allowable

The AISC specifications include fatigue allowable which also are accepted by the AWS building code. Therefore, designers have something other than the building code, bridges, with its automatic 10% lower allowable design stress, on which to base fatigue considerations.

Although developed for structures, these allowable are adaptable to the fatigue problems of machine tool makers, equipment manufacturers, and others who fabricate with welded steel. They cover a wide range of welded joints and members and not only provide values for various types of weld, but also take into consideration the strength of members attached by welds.

The conventional method of handling fatigue is based on a maximum fatigue stress. The AISC-suggested method is based on the range of stress. Either may be used in design; they will give comparable values. The AISC method is generally quicker.

Under the new approach, the allowable for members are designated M and for welds W. A tensile load is T, a compression load C, a reversal R, and shear S. In the chart used for determining values for allowable range of stress (fig. 14.41) there are four groups representing life. These are

1. 20 000 to 100 000 cycles
2. Over 100 000 to 500 000 cycles
3. Over 500 000 to 2 000 000 cycles
4. Over 2 000 000 cycles

And there are eight different categories representing type of joint and detail of member. The chart provides the allowable range in stress σ_{sr} or τ_{sr} , which value may be used in the conventional fatigue formulas. These formulas are

$$\sigma_{\max} = \frac{\sigma_{sr}}{1-K} \quad \text{or} \quad \sigma_{\max} = \frac{\tau_{sr}}{1-K}$$

where

$$\begin{aligned} K &= \frac{\text{min. stress}}{\text{max. stress}} = \frac{\text{min. force}}{\text{max. force}} \\ &= \frac{\text{min. moment}}{\text{max. moment}} = \frac{\text{min. shear}}{\text{max. shear}} \end{aligned}$$

Of course, the maximum allowable fatigue value used should not exceed the allowable for steady loading.

An alternative use of the allowable range of stress-taken from the table-is to divide it into the range of applied load. This will provide the required property of the section-area or section modulus. The section, as determined, must additionally be large enough to support the total load (dead and live load) at steady allowable stresses.

Reference to the chart of joint types and conditions and the table of allowable range of stress for the different categories (Appendix-X) will help make clear their use. Such reference also points up some of the new ideas introduced.

One new concept is that the fatigue allowable of a member, for example, a welded plate girder as shown by (2) in the chart (Appendix-X), is now determined by the allowable of the plate when connected by the fillet welds parallel to the

direction of the applied stress. M and W are equal, and the applicable category is B, rather than the allowable of plate without welds, category A.

If stiffeners are used on the girder, as in (4), the fatigue allowable of the web or flange is determined by the allowable in the member at the termination of the weld or adjacent to the weld, category C or D, depending on the shear value in the web.

The fatigue allowable of a flange plate at the termination of a cover plate, either square or tapered end, is represented by (5). The applicable category is E. The same category also applies to a plate or cover plate adjacent to the termination of an intermittent fillet weld, as in (6) and (39).

Groove welds in butt joints of plate loaded transversely to the weld are shown in (8) to (14). In (15), the groove weld is parallel to the load. In (10), (13), (14), and (28), an asterisk appears beside the category for reversal R of load. This means that a modified formula should be used for determining maximum fatigue stress:

$$\sigma_{\max} = \frac{\sigma_{sr}}{1 - 0.6K}$$

Using $0.6K$ provides a slight increase in fatigue allowable in the region of a complete reversal by changing the slope of the fatigue curve. The same butt joints used in a girder (3) do not show this increase in strength, and thus no asterisk appears beside R .

This approach gives, for the first time, fatigue allowable for partial-penetration groove welds, (16 to 918). Note by (19) and (20) that the fatigue allowable for a member with a transverse attachment is higher when the attachment is less than 2 in long, measured parallel to the axis of the load. Although there may be a similar geometric notch effect or abrupt change in section in both, it is the stress raiser that is important. The transverse bar in (19) is so short as far as the axis of the member and load are concerned that very little of the force is able to swing up and into the bar and then back down again. Consequently, the stress raiser is not severe. The longer bar attachment in (20), however, is sufficiently long to provide a path for the force through it and the connecting welds. Because of this

force transfer through the welds, there will be a higher stress raiser and, as a result, a reduction of the fatigue strength of the member.

Item (30) of the chart, which falls into category E, should not be confused with (37), category G. Both depict transverse fillet welds, but (30) provides a fatigue allowable for the member adjacent to the fillet weld, whereas (37) provides a fatigue shear allowable for the throat of the fillet weld.

Knowing that the steady strength of a transverse fillet is about a third stronger than that of a parallel fillet, one might question why the fatigue allowable for a parallel fillet, (34) and (35), category F, is the same as that for a transverse fillet (36) and higher than that for a transverse fillet (37), category G. The fatigue strength of the transverse fillet (36) is actually higher than that of a parallel fillet (34), but they both fall into the range covered by category F. However, there is a difference in the two transverse fillet welds in (36) and (37). In (36) there may be a slight stress raiser because of the pinching together of forces as they pass through the weld. But in (37) there is a greater tearing action at the root of the weld, thus producing lower fatigue strength and warranting a lower fatigue allowable.

Table I.c: Permissible stress of weld

No.	Type of weld stress	Permissible stress	Required stress level (1) (2)
COMPLETE PENETRATION GROOVE WELDS			
1	Tension normal to the effective throat	Same as base metal	Matching weld metal must be used. See table below.
2	Compression normal to the effective throat.	Same as base metal	Weld metal with a strength level equal to or one classification (10 ksi) less than matching weld metal may be used.
3	Tension or compression parallel to the axis of the weld	Same as base metal	Weld metal with a strength level equal to or less than matching weld metal may be used.
4	Shear on the effective throat	0.30 x Nominal tensile strength of weld metal (ksi) except stress on base metal shall not exceed 0.40 x yield stress of base metal.	
PARTIAL PENETRATION GROOVE WELDS			
5	Compression normal to effective throat.	Design not to bear 0.50xnormal tensile strength of weld metal (ksi) except stress on base metal shall not exceed 0.60xyield stress of	Weld metal with a strength level equal to or less than matching weld metal may be

WELD DESIGN OF HEAVY DUTY VEHICLE BODIES

		base metal. Designed to bear. Same as base metal	used.
6	Tension or compression parallel to axis of the weld. (3)	Same as base metal.	
7	Shear parallel to axis of weld	0.30xnominal tensile strength of weld metal (ksi) except stress on base metal shall not exceed 0.40xyield stress of base metal	
8	Tension normal to effective throat. (4)	0.30xnominal tensile strength of weld metal (ksi) except stress on base metal shall not exceed 0.60xyield stress of base metal.	

Table I:d

No.	FILLET WELDS(3)		
1	Stress on effective throat, regardless of direction of application of load.	0.30xnominal tensile strength of weld metal (ksi) except stress on base metal shall not exceed 0.40xyield stress of base metal.	Weld metal with a strength level equal to or less than matching weld metal may be used.
2	Tension or compression parallel axis of weld	Same as base metal	
PLUG AND SLOT WELDS			
3	Shear parallel to faying surface	0.30xnominal tensile strength of weld metal (ksi) except stress on base metal shall not exceed 0.40xyield stress of base metal	Weld metal with a strength level equal to or less than matching weld metal may be used.

- (1) For matching weld metal, see table below.
- (2) Weld metal, one strength level (10 KSI) stronger than matching weld metal may be used when using alloy weld metal on A242 or A588 steel to match corrosion resistance or coloring characteristics.
- (3) Fillet welds and partial penetration groove welds joining the component elements of built up members (ex. flange to web welds) may be designed without regard to the axial tensile or compressive stress applied to them.
- (4) Cannot be used in tension normal to their axis under fatigue loading. AWS bridge prohibits their use on any butt joint or any splice in a tension or compression member or splice in beams or girders, however, are allowed on corner joints parallel to axial force of components of built up members. Can not be used in girder splices.

Table I. e: Matching weld metal and base metal

Weld metal	60 or 70	70	80	100	110
Type of steel	A36;A53,Gr.B;A106,Gr.B; A131,Gr.A,B,C,CS,D,E; A193, Gr.B; A381, Gr. Y35; A500, Gr.A,B; A510; A516, Gr.55, 60;A524, Gr.65;A709, Gr.36; API 5L, Gr.B; API 5LX, Gr.42; ABS, Gr.A,B,D,CS,DS,E	A131, Gr.AH32, DH32, EH32, AH36,DH36, EH36; A242; A441; A516, Gr.65; 70; A537, Class 17; A572, Gr.42, 45, 50, 55; A588(4 in & under); A595, Gr.A,B,C; A606; A607, Gr.45, 50, 55; A618;A633, Gr.A,B,C, D(2-1/2 in & under); A709, Gr.50, 50W; API 2H; ABS Gr. AH32, DH32, EH32, AH36, DH36, EH36.	A572, Gr.60,65;A 537,class 2, A63, Gr.E	A514[over 1/2 in(63 mm) & under]; A709, Gr.100, 100W [2 1/2 to 4 in.(63 to 102 mm)]	A514[2 1/2 in(63 mm) & under]; A517; A709, Gr. 100, 100W [2 1/2 to 4 in (63 mm)]

This table summarizes the AISC specifications and the AWS structural welding code ("specification for the design, fabrication and erection of structural steel for buildings," American Institute of Steel Construction; AWS D.1-82, American Welding Society).

Table I. f: American welding society specification for welding electrodes.

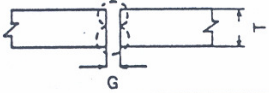
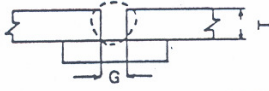
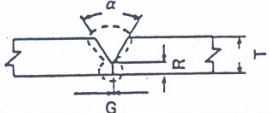
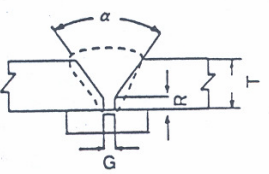
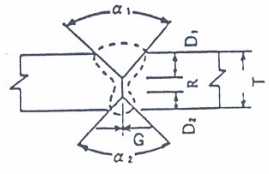
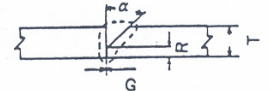
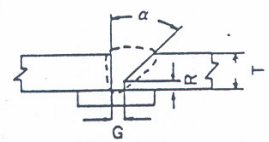
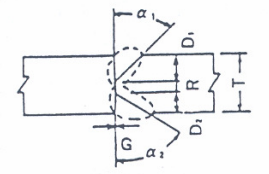
AWS No.	Yield, Ksi	Principal alloy	Remark
6010	66.5	Mn, Si	Piping, ships/Structures
7018	73.7	Mn, Si	For harder steels
8010	80-90	Mn, Ni	Pipe lines
10018	95.9	Mn, Ni, Mo	To weld manganese
308.15	65	Cr, Ni, Mn	For stainless steel
316-L15	68	Cr, Ni, Mn, Mo	For stainless steel

Table I.g: Fillet weld strength (AWS)

Base metal (ASTM)	Yield stress (Ksi)	Electrode	Allowable Shear stress (ksi)
A500A	-	AWS E60XX	18.0
A36, 53B	-	AWS E70XX	21.0
A527	36	AWS E80XX	24.0
A514 (>2.5 in)	50	AWS E90XX	27.0
A514 (<2.5 in)	100	AWS E100XX	30.0
A514 (<2.5 in)	-	AWS E110XX	33.0

APPENDICES-II

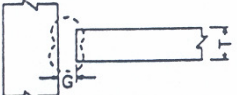
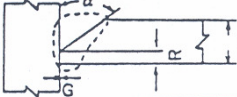

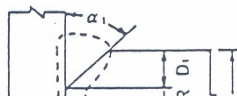
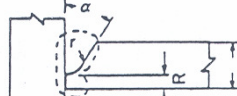

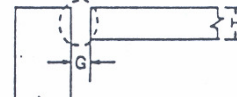
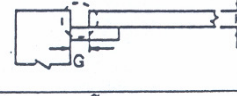
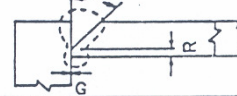
Shield Metal Arc Welding with Complete Joint Penetration

No.	Groove type	Applicable plate thickness (mm)	Welding position	Size (mm)	
1		$T \leq 6$	F H V O	G	$T/2$
2		$T \leq 6$	F H V O	G	T
3		$T \geq 6$	F H V O	G	0
				R	2
				α	60°
4		$T \geq 6$	F V O	G	6
				R	2
				α	45°
		$T \geq 12$	F V O	G	9
				R	2
				α	35°
5		$T \geq 16$	F H V O	G	0
				D_1	$2(T-R)/3$
				R	2
				D_2	$(T-R)/3$
				α_1	60°
				α_2	60°
6		$T = 6 \sim 20$	F H V O	G	0
				R	2
				α	45°
7		$T \geq 6$	F H V O	G	6
				R	2
				α	45°
		$T \geq 12$	F H V O	G	9
				R	2
				α	35°
8		$T \geq 12$	F H V O	G	0
				D_1	$2(T-R)/3$
				R	2
				D_2	$(T-R)/3$
				α_1	45°
				α_2	60°

(cont.) Shield Metal Arc Welding with Complete Joint Penetration

No.	Groove type	Applicable plate thickness (mm)	Welding position	Size (mm)	
9		$T \geq 16$	F	G	0
				R	2
				α	20°
			O	γ	6
				G	0
				R	2
H	α	45°			
	γ	6			
	γ	6			
10		$T \geq 16$	F	G	0
				R	2
				α	30°
			O	γ	9
				G	0
				R	2
H	α	45°			
	γ	9			
	γ	9			
11		$T \geq 30$	F	G	0
				D_1	$(T-R)/2$
				R	2
				D_2	$(T-R)/2$
				α_1	20°
				α_2	20°
			O	γ_1	6
				γ_2	6
				G	0
				D_1	$(T-R)/2$
				R	2
				D_2	$(T-R)/2$
H	α_1	45°			
	α_2	45°			
	γ_1	6			
	γ_2	6			
	γ_1	6			
	γ_2	6			
12		$T \geq 30$	F	G	0
				D_1	$2(T-R)/3$
				R	2
				D_2	$(T-R)/3$
				α_1	30°
				α_2	30°
			O	γ_1	9
				γ_2	9
				G	0
				D_1	$2(T-R)/3$
				R	2
				D_2	$(T-R)/3$
H	α_1	45°			
	α_2	45°			
	γ_1	9			
	γ_2	9			
	γ_1	9			
	γ_2	9			

(cont.) Shield Metal Arc Welding with Complete Joint Penetration

No.	Groove type	Applicable plate thickness (mm)	Welding position	Size (mm)	
				G	Other
13		$T \leq 6$	F H V O	G	$T/2$
14		$T = 6 \sim 20$	F H V O	G	0
				R	2
				α	45°
15		$T \geq 6$	F H V O	G	6
				R	2
				α	45°
		$T \geq 12$	G	9	
			R	2	
			α	35°	
16		$T \geq 12$	F H V O	G	0
				D_1	$2(T-R)/3$
				R	2
				D_2	$(T-R)/3$
				α_1	45°
17		$T \geq 16$	F O	G	0
				R	2
				α	30°
				γ	9
18		$T \geq 30$	F O	G	0
				D_1	$2(T-R)/3$
				R	2
				D_2	$(T-R)/3$
				α_1	30°
				α_2	45°
				γ_1	9
γ_2	9				
19		$T \leq 6$	F H V O	G	$T/2$
20		$T \leq 6$	F V	G	T
21		$T \leq 50$	F H V O	G	0
				R	2
				α	60°

(cont.) Shield Metal Arc Welding with Complete Joint Penetration

No.	Groove type	Applicable plate thickness (mm)	Welding position	Size (mm)	
22		$T \geq 6$	F	G	0
			H	R	2
				α	45°
		$T \geq 12$	V	G	9
			O	R	2
				α	35°
23		$T = 6 \sim 20$	F	G	0
			H	R	2
				α	45°
			V	G	9
				O	R
			α	35°	
24		$T \geq 6$	F	G	6
			H	R	2
				α	45°
		$T \geq 12$	V	G	9
			O	R	2
				α	35°
25		$T \geq 12$	F	G	0
			H	D ₁	$2(T-R)/3$
				R	2
			V	D ₂	$(T-R)/3$
				α_1	45°
			O	α_2	60°
26		$T \geq 16$	F	G	0
				R	2
				α	20°
			H	G	0
				R	2
				α	45°
V	γ	6			
	γ	6			
	γ	6			
27		$T \geq 16$	F	G	0
				R	2
				α	30°
			H	G	0
				R	2
				α	45°
V	γ	9			
	γ	9			
	γ	9			
28		$T \geq 30$	F	G	0
				D ₁	$2(T-R)/3$
				R	2
				D ₂	$(T-R)/3$
				α_1	30°
				α_2	45°
			O	γ_1	9
				γ_2	9
				G	0
				D ₁	$2(T-R)/3$
				R	2
				D ₂	$(T-R)/3$
H	α_1	45°			
	α_2	45°			
	γ_1	9			
	γ_2	9			
	γ_1	9			
	γ_2	9			

APPENDICES-III

Submerged Arc Welding with Complete Penetration

No.	Groove type	Applicable plate thickness (mm)	Welding position	Size (mm)	
1		$T \leq 12$	F	G	0
2		$T \leq 12$	F	G	3~6
3		$T \leq 25$	F	G	0
				D	$T - R$
				R	6~8
				α	60° ~ 90°
4		$T \leq 50$	F	G	6~10
				R	2
				α	30°
5		$T \leq 50$	F	G	0
				D_1	$(T - R) / 2$
				R	6~8
				D_2	$(T - R) / 2$
				α_1	60° ~ 90°
6		$T \leq 50$	F	G	6~10
				R	2
				α	30° ~ 45°
7		$T \geq 30$	F	G	0
				R	6~8
				α	20° ~ 30°
8		$T \leq 50$	F	G	0
				D_1	$(T - R) / 2$
				R	6~8
				D_2	$(T - R) / 2$
				α_1	20° ~ 30°
				α_2	20° ~ 30°
r_1, r_2	4~8				

(cont.) Submerged Arc Welding with Complete Penetration

No	Groove type	Applicable plate thickness (mm)	Welding position	Size (mm)	
9		$T \leq 12$	F H	G	0
10		$T \leq 20$	F	G	0
				R	5
				α	60°
11		$T \leq 50$	F	G	6~10
				D	T - R
				R	2
				α	30° ~ 40°
12		$T \leq 50$	F	G	0
				D ₁	(T - R)/2
				R	5
				D ₂	(T - R)/2
				α ₁	60°
				α ₂	60°
13		$T \leq 12$	F	G	0
14		$T \leq 12$	F	G	3~6
15		$T \leq 50$	F	G	0
				R	6~8
				α	60° ~ 90°
16		$T \leq 50$	F	G	6~10
				D	T - R
				R	2
				α	30°
17		$T \leq 20$	F	G	0
				D	T - R
				R	5
				α	50°
18		$T \leq 50$	F	G	6~10
				R	2
				α	30° ~ 45°

(cont.) Submerged Arc Welding with Complete Penetration

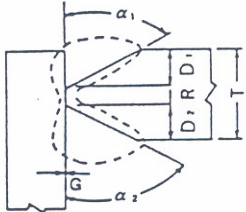
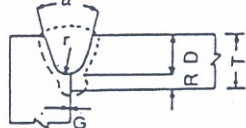
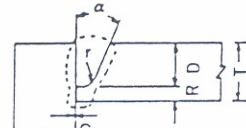
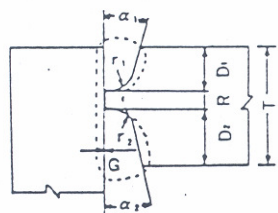

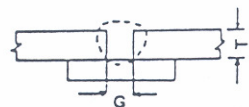
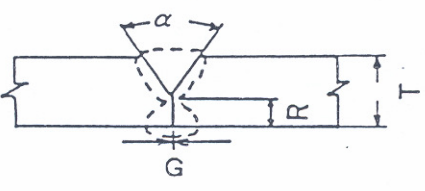
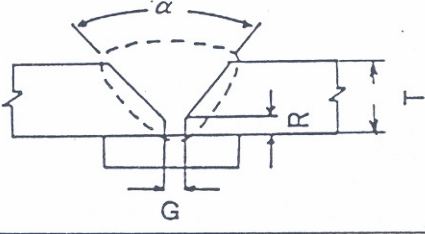
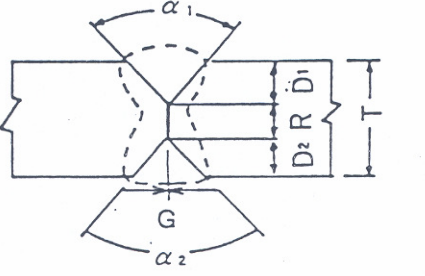
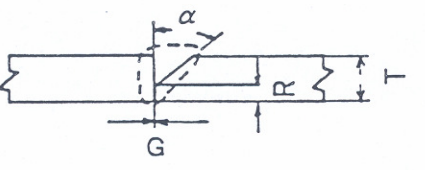
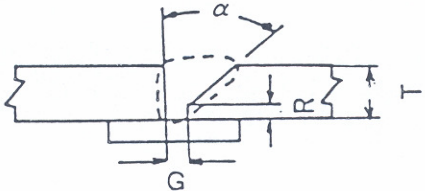
No.	Groove type	Applicable plate thickness (mm)	Welding position	Size (mm)	
				G	
19		$T \leq 50$	F	G	0
				D_1	$(T-R)/2$
				R	5
				D_2	$(T-R)/2$
				α_1	60°
				α_2	60°
20		$T \geq 30$	F	G	0
				D	$T-R$
				R	6~8
				α	$20^\circ \sim 30^\circ$
				γ	4~8
21		$T \geq 30$	F	G	0
				D	$T-R$
				R	6~8
				α	20°
				γ	12
22		$T \leq 50$	F	G	0
				D_1	$(T-R)/2$
				R	6~8
				D_2	$(T-R)/2$
				α_1	20°
				α_2	20°
				γ_1	12
				γ_2	12

Table 1.6 Gas Metal Arc Welding with Complete Joint Penetration

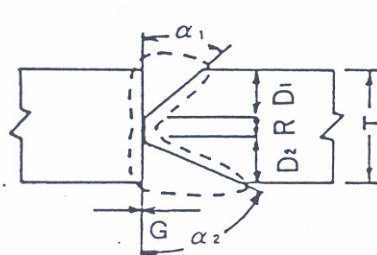
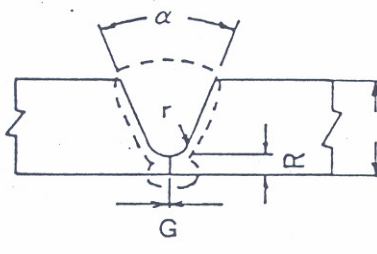
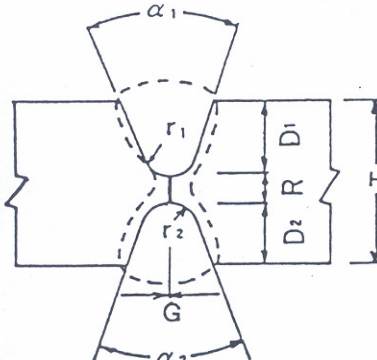
No.	Groove type	Applicable plate thickness (mm)	Welding position	Size (mm)	
				G	
1		$T \leq 6$	F H V O	G	$T/3$
2		$T \leq 9$	F H	G	$2T/3$
		$T \geq 6$	V O		T

APPENDICES-IV

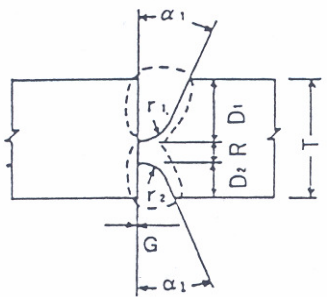
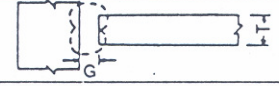
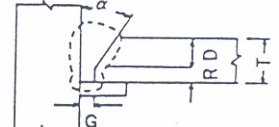
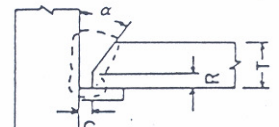
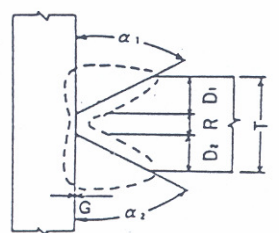
Gas Metal Arc Welding with Complete Penetration

No.	Groove type	Applicable plate thickness (mm)	Welding position	Size (mm)	
3		$T \geq 6$	F H	G	0
				R	3
				α	60°
			V O	G	0
				R	2
				α	60°
4		$T \geq 6$ $T \geq 16$	F H V O	G	6
				R	2
				α	45°
			F H V O	G	9
				R	2
				α	35°
5		$T \geq 16$	F H	G	0
				D_1	$2(T-R)/3$
				R	3
				D_2	$(T-R)/3$
				α_1	60°
				α_2	60°
			V O	G	0
				D_1	$2(T-R)/3$
				R	2
				D_2	$(T-R)/3$
				α_1	60°
				α_2	60°
6		6 ~ 20	F H V O	G	0
				R	3
				α	55°
			V O	G	0
				R	2
				α	5°
7		$T \geq 6$	F H V O	G	6
				R	2
				α	5°
		$T \geq 16$	F H V O	G	9
				R	2
				α	25°

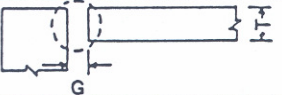
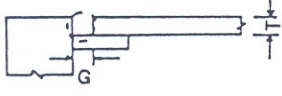
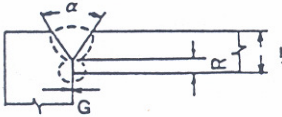


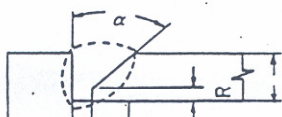
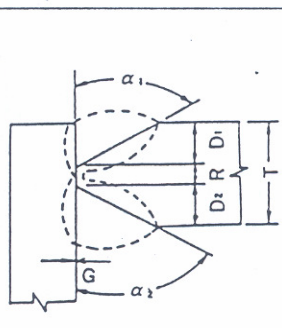
(cont.) Gas Metal Arc Welding with Complete Penetration

No.	Groove type	Applicable plate thickness (mm)	Welding position	Size (mm)					
				Symbol	Value				
8		$T \geq 16$	F	G	0				
				D_1	$2(T-R)/3$				
				R	3				
				H	D_2	$(T-R)/3$			
					α_1	55°			
					α_2	60°			
			V	G	0				
				D_1	$2(T-R)/3$				
				R	2				
				O	D_2	$(T-R)/3$			
					α_1	45°			
					α_2	60°			
9		$T \geq 16$	F	G	0				
				R	4				
				α	20°				
				r	6				
			V	G	0				
				R	3				
				O	α	40°			
					r	6			
					10		$T \geq 30$	F	G
				D_1					$(T-R)/2$
R	4								
D_2	$(T-R)/2$								
H	α_1	20°							
	α_2	20°							
	r_1	6							
	r_2	6							
	V	G	0						
		D_1	$(T-R)/2$						
R		3							
O		D_2	$(T-R)/2$						
		α_1	40°						
		α_2	40°						
r_1	6								
r_2	6								

(cont.) Gas Metal Arc Welding with Complete Penetration

No.	Groove type	Applicable plate thickness (mm)	Welding position	Size (mm)		
11		$T \geq 30$	F	G	0	
				D_1	$2(T-R)/3$	
				R	4	
				D_2	$(T-R)/3$	
				α_1	30°	
				α_2	45°	
			H	r_1	9	
				r_2	9	
				V	G	0
					D	$2(T-R)/3$
					R	3
					D	$(T-R)/3$
α_1	45°					
α_2	45°					
O	r_1	9				
	r_2	9				
12		$T \leq 6$	F H V O	G	$T/3$	
13		$T = 6 \sim 20$	F H V O	G	0	
				R	3	
				α	55°	
			V O	G	0	
				R	2	
				α	45°	
14		$T \geq 6$	F H	G	6	
				R	2	
		$T \geq 12$	V O	G	6	
				R	2	
		α	35°			
		15		$T \geq 16$	F	G
D_1	$2(T-R)/3$					
R	3					
D_2	$(T-R)/3$					
α_1	55°					
H	α_2				60°	
	V				G	0
					D_1	$2(T-R)/3$
					R	2
					D_2	$(T-R)/3$
α_1		45°				
O	α_2	60°				
	16	$T \geq 30$	F	G	0	
D_1				$2(T-R)/3$		
R				4		
D_2				$(T-R)/3$		
H			α_1	30°		
			α_2	45°		
			r_1	9		
			r_2	9		

(cont.) Gas Metal Arc Welding with Complete Penetration

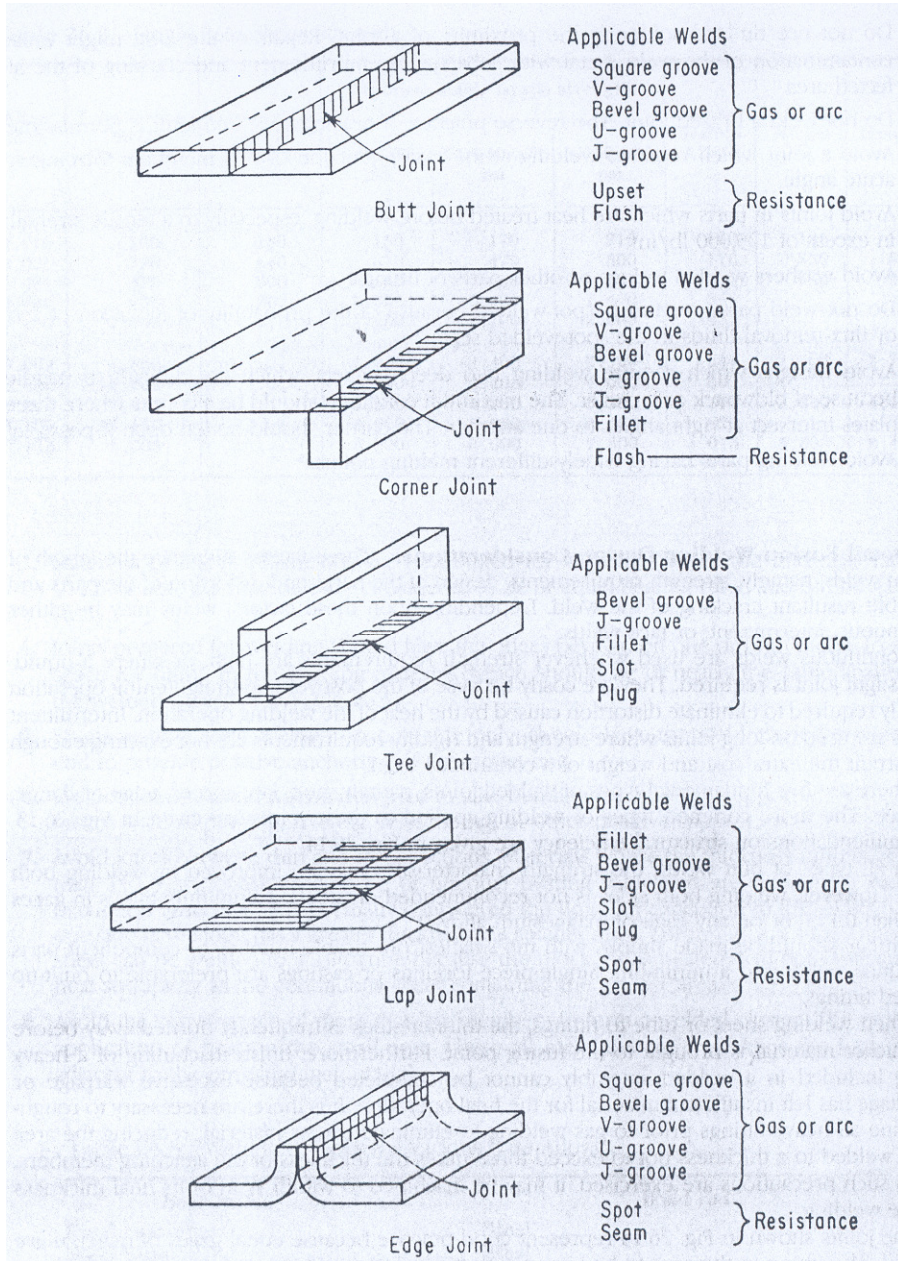
No.	Groove type	Applicable plate thickness (mm)	Welding position	Size (mm)	
17		$T \leq 6$	F H V O	G	$T/3$
18		$T \leq 9$	F H	G	$2T/3$
		$T \leq 6$	V O	G	T
19		$T = 6 \sim 20$	F H V O	G	0
				R	3
				α	55°
			V O	G	0
				R	2
				α	45°
20		$T \leq 50$	F H V O	G	0
				R	3
				α	60°
			V O	G	0
				R	2
				α	60°
21		$T \geq 6$	F H V O	G	6
				R	2
				α	45°
		$T \geq 16$	F H V O	G	9
				R	2
				α	35°
22		$T \geq 6$	F H V O	G	6
				R	2
				α	45°
		$T \geq 16$	F H V O	G	9
				R	2
				α	35°
23		$T \geq 16$	F H	G	0
				D_1	$2(T-R)/3$
				R	3
				D_2	$(T-R)/3$
				α_1	55°
				α_2	60°
			V O	G	0
				D_1	$2(T-R)/3$
				R	2
				D_2	$(T-R)/3$
				α_1	45°
				α_2	60°

(cont.) Gas Metal Arc Welding with Complete Penetration

No.	Groove type	Applicable plate thickness (mm)	Welding position	Size (mm)		
24		$T \geq 16$	F	G	0	
				R	4	
				α	20°	
			H	r	6	
				V	G	0
					R	3
O	α	40°				
	r	6				
25		$T \geq 30$	F	G	0	
				D_1	$2(T-R)/3$	
				R	4	
				D_2	$(T-R)/3$	
				α_1	30°	
				O	α_2	45°
			r_1		9	
			r_2		9	
			H	G	0	
				D_1	$2(T-R)/3$	
				R	3	
				D_2	$(T-R)/3$	
V	α_1	45°				
	α_2	45°				
	r_1	9				
	r_2	9				

APPENDICES-V

Welds Applicable to Basic Joints



APPENDICES-VI

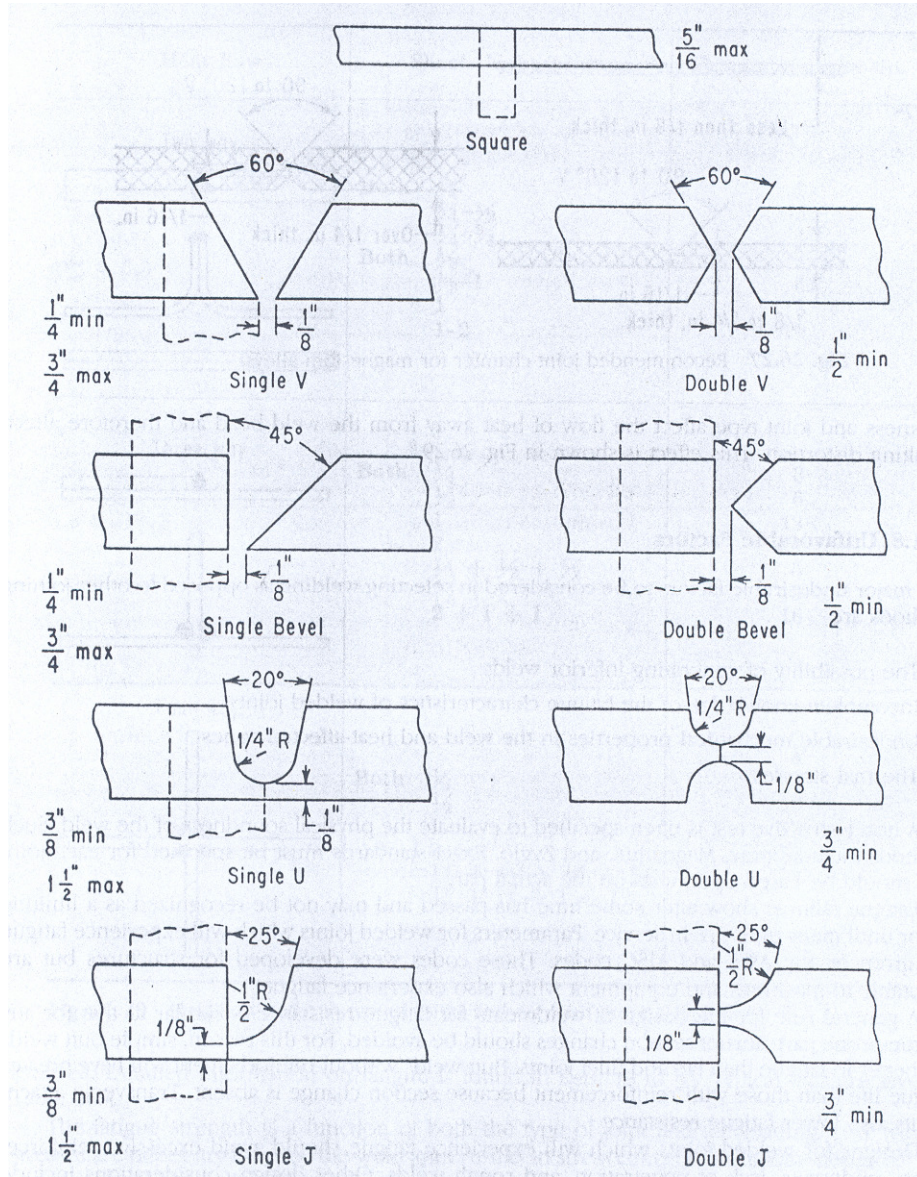
Structural Efficiency of Various Types of Welds

Type of weld	Illustration	Sheet gage	Efficiency in			Fatigue resistance	Application
			Shear	Tension	Compression		
Square butt welded one side		Up to 0.124	High	High	High	Fair	All general applications. The choice depends upon the material, gage, loading, fatigue requirements, etc.
Single V welded one side		0.125 and over	High	High	High	Good	
Single bevel welded one side		0.125 and over	High	High	High	Good	
Double V welded both sides		0.375 and over	High	High	High	Good	
Open-square groove corner		Up to 0.065	Medium	Low	High	Poor	
Single V corner fillet		0.065 and over	Medium	Low	Poor	Closed structures and heavy-gage tanks
Outside or inside single fillet		Up to 0.094	High	Low	Poor	
Single fillet tee		Any gage	Medium	Low	Low	Poor	General purposes
Double fillet tee		Any gage	High	High	High	Good	
Edge fillet weld		Any gage	Medium	Low	Fair	Closed structure and heavy-gage tanks
Double-lap fillet		Up to 0.250	High	High	Fair	
Flange weld		Up to 0.081	Medium	Low	Poor	Tanks and closed nonstructural parts

Flange height	Material gage	Root Opening B 0.064 gage and less, no gap 0.064-0.124 gage, gap = 1/2 sheet thickness
4 X material gage	0.040 or less	
3 X material gage	0.041-0.081	




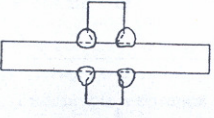
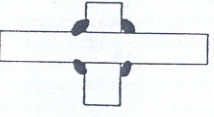
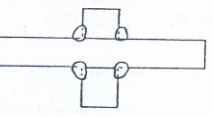
APPENDICES-VII

Types of Joints



APPENDICES-VIII

Relative Fatigue Strength of Various Joints

Type of joint	Notes	Endurance limit, tons/in. ²	
		Tension/ compression	Tension only
	Weld machine flush	±9.0	7.0 ± 7.0
	As welded	±7.0	5.75 ± 5.75
	Incomplete root fusion	±5.0	4.0 ± 4.0
	Complete root fusion	±5.5	4.75 ± 4.75
	Incomplete root fusion	±3.7	3.5 ± 3.5
	No joint preparation	±2.25	2.0 ± 2.0

APPENDICES-IX

Weld Stress Calculations Formula

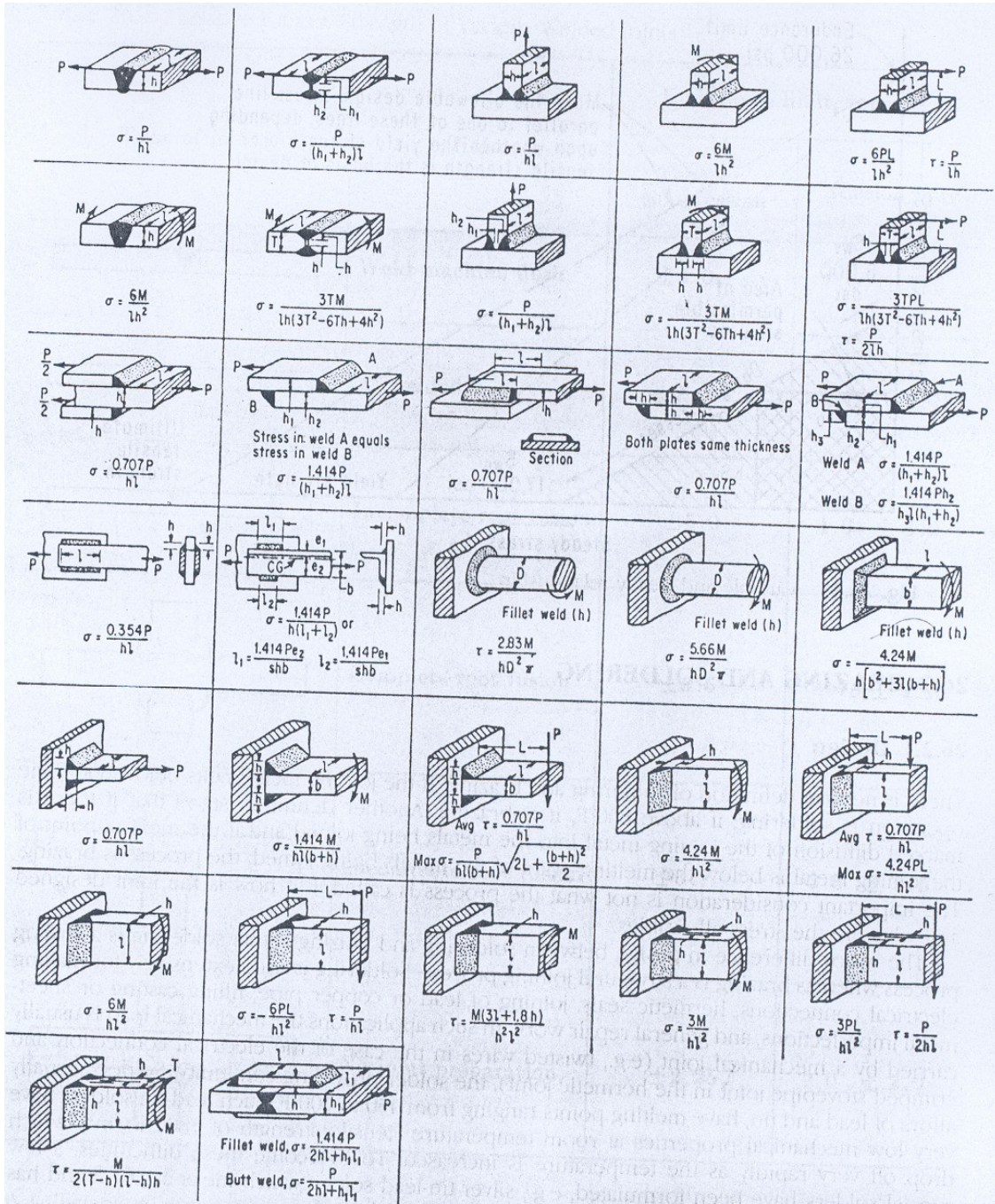


Fig. 26.31 Stress calculations.

- σ = normal stress lb/in²
- τ = shear stress, lb/in²
- M = bending moment, in·lb
- P = external load, lb
- L = linear distance, in
- h = size of weld, in
- l = length of weld, in

APPENDICES-X

The AISC allowable range of stress σ_{SF} or τ_{SF}

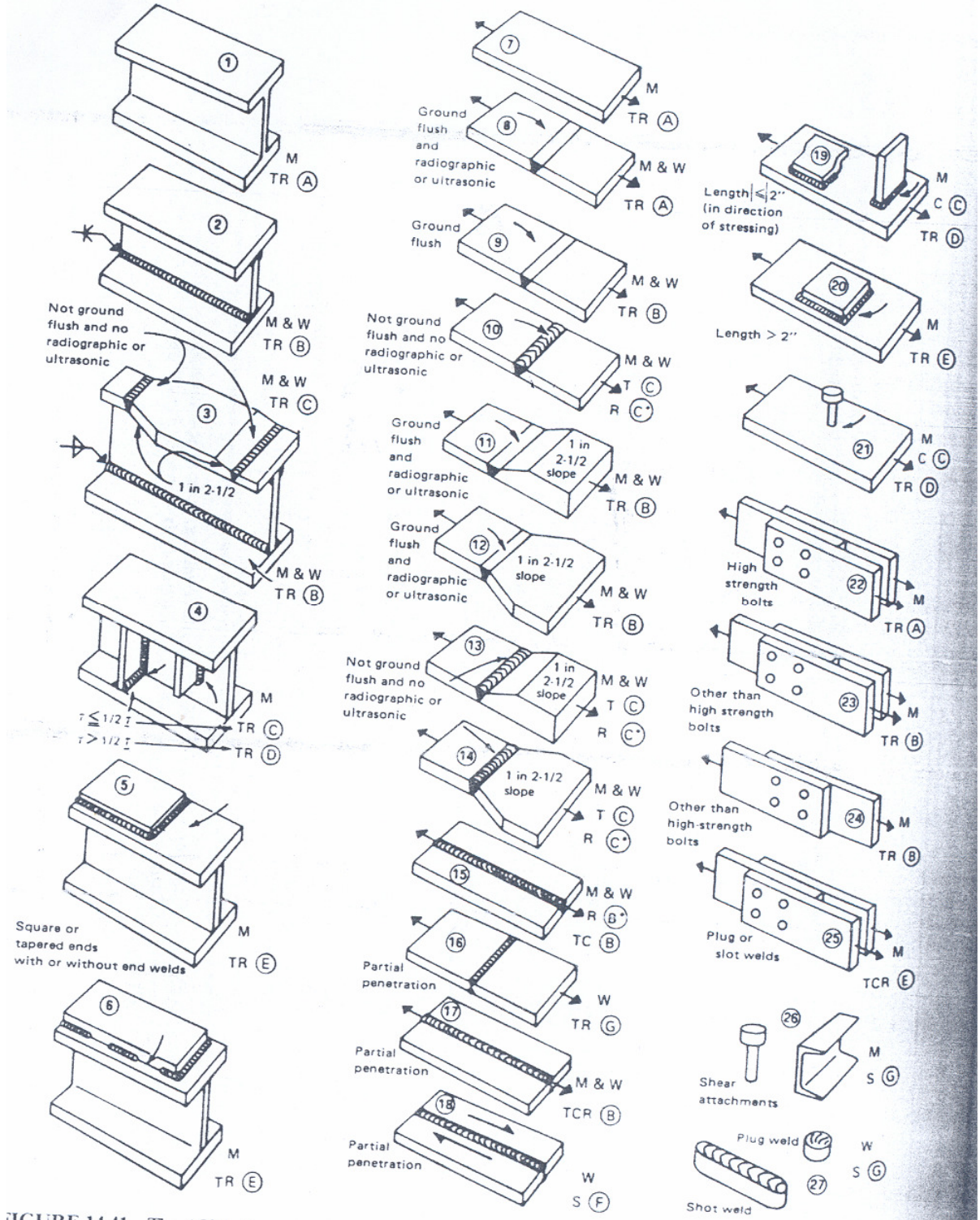
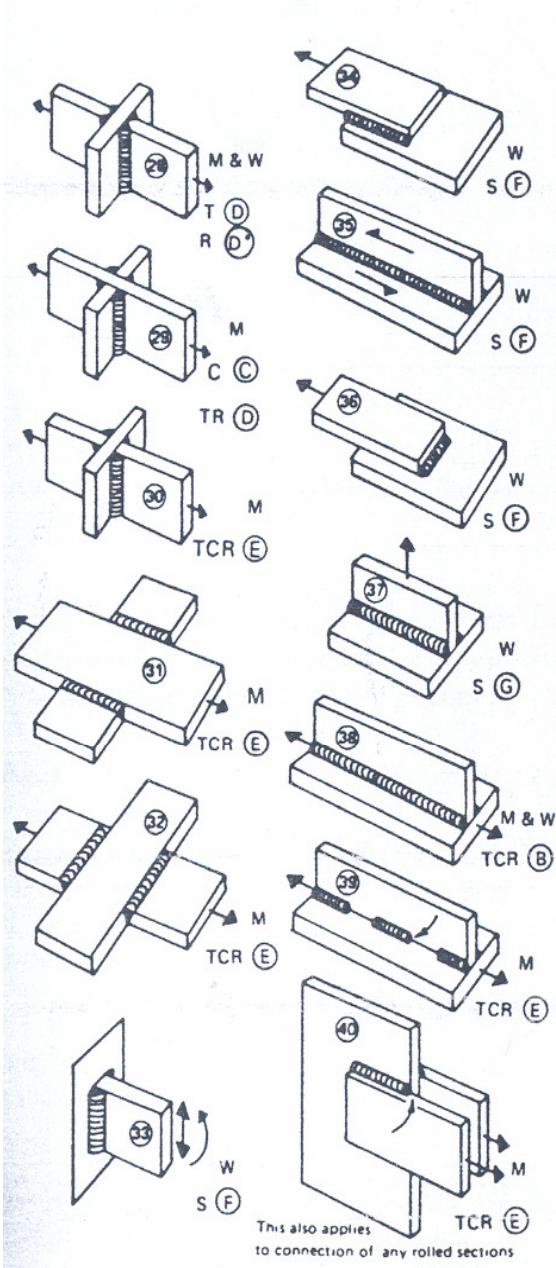


FIGURE 14.11

(cont.) The AISC allowable range of stress σ_{sr} or τ_{sr}



	20 000 to 100 000 ~	100 000 to 500 000 ~	500 000 to 2 000 000 ~	over 2 000 000 ~
(A) A514	45	35	25	25
(A)	40	32	24	24
(B)	33	25	17	15
(C)	28	21	14	12
(D)	24	17	10	9
(E)	17	12	7	6
(F)	17	14	11	9
(G)	15	12	9	8

But shall not exceed steady allowables

Allowable fatigue stress

$$\sigma_{max} = \frac{\sigma_{sr}}{1 - K}$$

For those categories marked with an asterisk (*) in the case of a reversal use

$$* \sigma_{max} = \frac{\sigma_{sr}}{1 - 0.6K}$$

σ_{max} or τ_{max} = maximum allowable fatigue stress

σ_{sr} or τ_{sr} = allowable range of stress, from table

$$K = \frac{\sigma_{min}}{\sigma_{max}} = \frac{M_{min}}{M_{max}} = \frac{F_{min}}{F_{max}} = \frac{T_{min}}{T_{max}} = \frac{V_{min}}{V_{max}}$$

- Curved arrow indicates region of application of fatigue allowables
- Straight arrows indicate applied forces
- Grind in the direction of stressing only

When slope is mentioned (ex. 1 in 2-1/2 this is always the maximum value. Less slope is permissible.

- S = shear
- T = tension
- C = compression
- R = reversal
- M = stress in metal
- W = stress in weld
- τ = allowable steady shear stress

APPENDICES-XI

Sample Data of ESAB Welding Handbook

ESAB E70S-6

Description

A copper-coated, manganese-silicon bearing electrode for the GMAW of unalloyed steels, such as general structural steels with a minimum tensile strength of 530 MPa, and for fine-grained, carbon-manganese steels with minimum yield strength of 420 MPa. OK Autrod 12.51 can be welded with Ar / 20 CO₂ or pure CO₂ as the shielding gas. The mechanical properties quoted here are welded with Ar / 20 CO₂ as the shielding gas.

Welding current

DC(+)

Approvals

ABS 3SA, 3YSA
 BV SA, 3YM
 CO ..
 DB 42.039.06
 DnV III YMS
 DS E 51 3
 GL 3YS
 LR 3S, 3YS
 RINa SG 52 3
 RS 3YMS,K6SM
 PRS 3YS
 SFS GS2-C1-51-6,GS2-M
 SS 143403, 143423
 TUV
 UDT

Classifications

AWS A5-18-93 ER70S-6
 EN 440 G 38 2 C G3Si
 G 42 3 M G3Si

Wire composition

C	Si	Mn
0.08	0.9	1.5

Typical properties of weld metal

Yield stress 475 MPa
 Tensile strength 560 MPa
 Elongation 24%

Charpy V

Test temps.	Impact values
+20 °C	120J
0 °C	100J
-20 °C	80J
-40 °C	50J

Welding parameters

Diameter (mm)	Wire feed (m/min.)	Welding current (Amp.)	Arc voltage (volt)	Deposition rate Kg weld metal/hr.
0.6	5.5-13	30-100	15-20	0.7-1.7
0.8	3.2-13	60-200	18-24	0.8-3.0
0.9	3.0-12	70-250	18-26	0.9-3.6
1.0	2.7-15	80-300	18-32	1.0-5.6

WELD DESIGN OF HEAVY DUTY VEHICLE BODIES

1.2	2.3-15	120-380	18-34	1.2-8.0
1.4	2.5-15	150-420	22-36	1.7-8.6
1.6	3.2-12	225-550	28-38	3.0

APPENDICES-XII
QUESTIONERS

1. ORGANIZATIONAL PROFILE

1.1 Brief account of your organizational profile. (Just to be attached to the response of the questioner?)

2. WELD DESIGN

2.1 For the fabrications you carry out, do you have weld design?

2.2 How do you determine the weld sizes, specially, on critically loaded components?

2.3 How do you select the electrode (filler) material (its type)?

2.4 How do you select the electrode size?

2.5 Is there any standard code you adapt for your weld design (fabrication)?

2.6 How do you match the parent metal material with filler material?

2.7 What type of material do you use for your main product fabrication?

_____.

_____.

3 WELDING PROCESS

3.1 What welding processes do you use?

_____.

3.2 How did you select this process?

_____.

3.3 What is the disadvantage and advantage of this welding process over others known?

_____.

3.4 By this process, on average, how many products do you produce per day? [Rate of production or rate of electrode deposition, Kg/hr or length of weld, m/sec.]

_____.

3.5 How do you analyze the effect of this welding process on the quality of your product?

_____.

4 WELDMET PREPARATION

4.1 What is the range of the thickness of metal you employ in the welding fabrication? [Min. to max.]

_____.

4.2 Is there any standard you adapt to carry out material preparation for welding?

_____.

4.3 What devices do you employ to make material preparation for welding?

_____.

5 WELD QUALITY

5.1 What measures do you take to avoid the formation of weld porosity?

_____.

5.2 What measures do you take to avoid the slag inclusion?

_____.

5.3 What measures do you take to avoid weld distortions?

_____.

5.4 What are the frequent welding related problems observed in your fabrication process? What measures did you take to remedy them?

_____.

_____.

5.5 How do you keep welding electrodes, specially, if it is flux shielded one?

_____.

_____.

6 TESTING AND INSPECTION

6.1 Do you carry out any welding test on your weld? If so what sort of testing?

_____.

_____.

6.2 How do you carry out the quality control on your weld fabrication products?

_____.

_____.

6.3 Is there any standard you adapt for weld testing and inspection? If so explain.

_____.

_____.

7 CODES AND STANDARDS

7.1 Is there any welding code you adapt to carry out your welding fabrication? If so mention it.

_____.

_____.

7.2 If you have not adapted any weld code yet, what is your possible reason?

7.3 What is the impact of not adapting any welding code on your product? if any

7.4 Do you have information on the welding codes available in line of your weld fabrication?

8 WELDER QUALIFICATION AND CERTIFICATION

8.1 What is the range of qualification of your welders?

8.2 Are your welders certified on a specific welding?

8.3 If any of your welder is not certified what is its impact on welding fabrication?

9 WELD CRACK [INTERNAL AND EXTERNAL]

9.1 Have you any feed back on weld crack of your welding fabrication product?

9.2 Have you analyzed the possible cause of the crack? If so mention it.

9.3 What are the measures you take to avoid internal and external weld cracks?
