

Distortion and Residual Stress

PART OF THE CWB CERTIFICATE PROGRAMS



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Module 7

WELDING DISTORTION AND RESIDUAL STRESSES

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WELDING DISTORTION AND RESIDUAL STRESSES

The establishment and control of a proper welding procedure is highly important if sound economical welding is to be obtained. It is perhaps the most important function of the welding engineer or supervisor and will call upon all his knowledge and experience.

Since it is often impossible to establish a satisfactory procedure for an unsatisfactory design, this and the following lessons are of equal interest to the designer since he must share with the supervisor the responsibility for the end product.

The development of a welding procedure should start with the understanding that the heat of welding will produce expansion, contraction and stresses and consequently its major objects will be to:

1. Maintain dimensions by controlling distortion;
2. Reduce internal residual welding stresses.

Obviously, welding procedure will involve welding method or process, base material, joint design and preparation, filler metal, current values, welding technique, heat treatment, etc., but even more important it has to do with the pattern of heat input to the job, as determined by the sequence of assembly and sequence of welding.

The effect of each of these factors must be comprehended and the procedure planned accordingly, first of all to minimize distortion and stresses.

The procedure once planned, and if necessary, checked and altered by trial, should be clearly laid out and definitely and purposefully followed.

Contraction will produce either distortion or stress, or both. Distortion, if excessive, may exceed dimensional tolerances, and stress, if excessive, may produce cracking. Both, in their extreme, must be avoided. They can be best avoided by knowing the fundamentals involved and using these principles plus common sense and experience in actual practice.

Expansion and Contraction

The expansion and contraction movements of heated metal may vary simply illustrated by considering the movements of a free metal bar as shown at A in Fig.1. Heat applied at any point on the bar causes it to lengthen; when the heat is removed the bar cools and contracts to its original length.

Actually heated metal expands volumetrically - that is, in all directions - the amount of expansion in any direction being proportional to the dimensions. Therefore, in the case of this metal bar there is an increase in both diameter and length. Only the increase in length is shown in the example because, the length being considerably greater than the diameter, the increase in diameter is negligible compared with the increase in length.

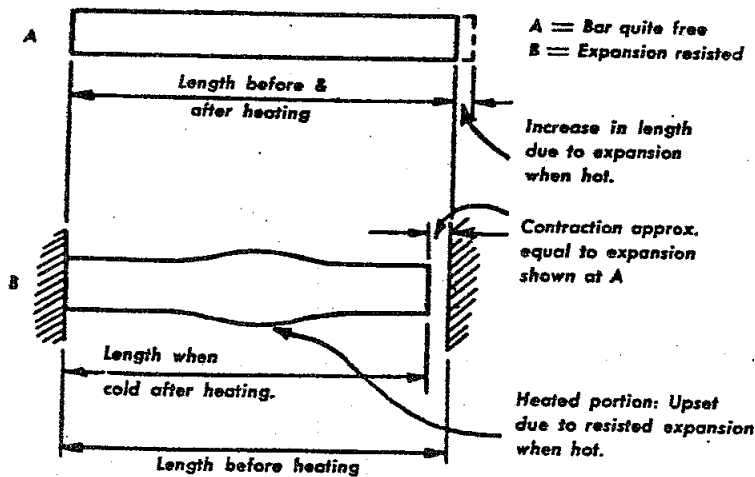


Fig. 1
Behaviour of Metal Bar When Heated and Cooled Under Different Conditions.

At high temperatures metal becomes plastic and may be compared to a piece of rubber in behaviour, that is, compression in one direction causes expansion in other directions. Therefore, in the case of the above mentioned bar, if lengthwise movement is prevented, expansion in other directions results. This is shown at B, by an increase in diameter of the heated portion, because this part has to absorb the volume of metal which was represented by the longitudinal expansion, as shown at A. The prevented expansion produces just the same effect as if the bar were allowed to expand longitudinally and then the ends placed between the jaws of a vise and compressed to its original length. The upsetting (i.e., swelling of the heated part) is known as permanent deformation, that is, it will not disappear when the bar cools. Therefore, when the bar is cold it will be shorter by an amount equal to the expansion which would have taken place if the bar had been free.

In the above examples we have considered (a) free expansion and contraction and (b) restricted expansion and free contraction. Now let us consider what happens when expansion and contraction are both resisted, that is, when the ends of the bar are gripped, as shown in Fig. 2, so that they will not allow either expansion or contraction to take place.

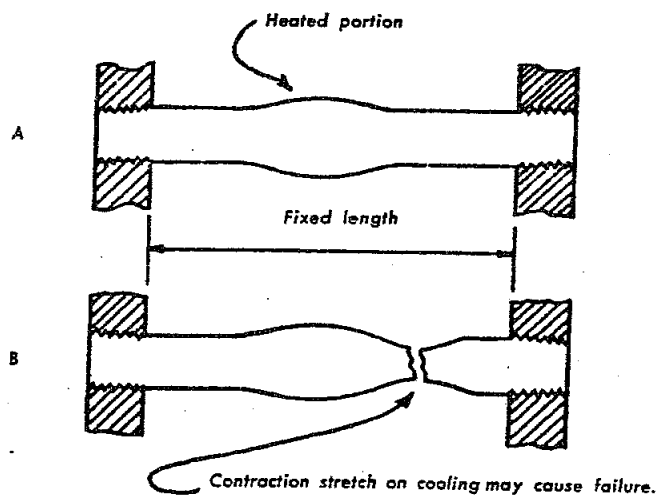


Fig. 2
Behaviour of Metal Bar When Heated and Cooled Under Conditions in Which Expansion and Contraction are Prevented.

A = Expansion prevented: causes upsetting when hot.

B = Upsetting remains on cooling and bar stretches.

When heat is applied the bar will upset since it cannot expand lengthwise, Fig. 2A. When it is cooled the upset portion will remain and since the bar is still rigidly held, it must stretch to the extent that it has been shortened by upsetting. If the metal is not sufficiently ductile and able to take this stretch, it will crack and fail. The action is just the same as if the bar had been allowed to contract fully and then were rigidly gripped and pulled back to its original length. Inevitably it must stretch and perhaps break in doing so.

Stress

The above brings us to the point of considering the effect of expansion and contraction. Free expansion and contraction does not disturb the metal but when either of these movements is resisted externally, the metal is stressed (refer to Figs. 1 and 2). Stress is a measure of the intensity of the resistance of the metal to either compression or stretching. For example, when a piece of metal is compressed, a compressive stress is set up; on the other hand, stretching sets up a tensile stress. When a piece of metal has cooled out under restraint, that is, when contraction has been prevented and the metal stretches but does not fail, it will have a residual (tensile) stress set up within it. If it fails, of course, no resisting stress remains.

Most metals are able to withstand an almost unlimited amount of compression. At high temperatures the compression stress may cause the softened metal to flow or deform (as in Figs. 1B and 2A) but failure is unlikely even under considerable loads. On the other hand they have only a very limited ability to stretch, and if the tensile stress to which they are subjected is too great, failure may occur, as shown in Fig. 2B.

The points which now should be quite clear are: (a) expansion and contraction are proportional to the dimensions of the heated areas; (b) restrained expansion and contraction cause deformation and stresses in metal, (c) restrained contraction may set up sufficient stress to cause failure if the metal is not ductile enough to accommodate the stretch.

Transverse Contraction (Shrinkage). Angular Distortion

Consider a V groove joint as shown in Fig. 3A, which is unrestricted, i.e., free to move as required by weld contraction. After welding, this joint will tend to assume the shape shown in B, the angular distortion being caused by the non-uniform contraction of weld metal due to the greater width of the top of the weld compared with the root of the V. If the weld metal could be deposited to form a more uniform section between the edges, as shown at C and D, there would (in theory) be no angular deformation, only uniform contraction across the joint.

Likewise it will be appreciated that in fillet welds the distortion resulting from contraction will be as in F and G for a joint set up as in E, Fig. 3.

Another example of transverse contraction or shrinkage is shown in Fig. 4A. If two plates being butt-welded together are not too heavy or held together, and are thus free to move, they will be drawn closer together by the contraction of the weld metal. The amount of drawing, to a certain extent, depends upon the speed of welding. As a rule the greater the speed, the less the amount. The speed at which the plates will not

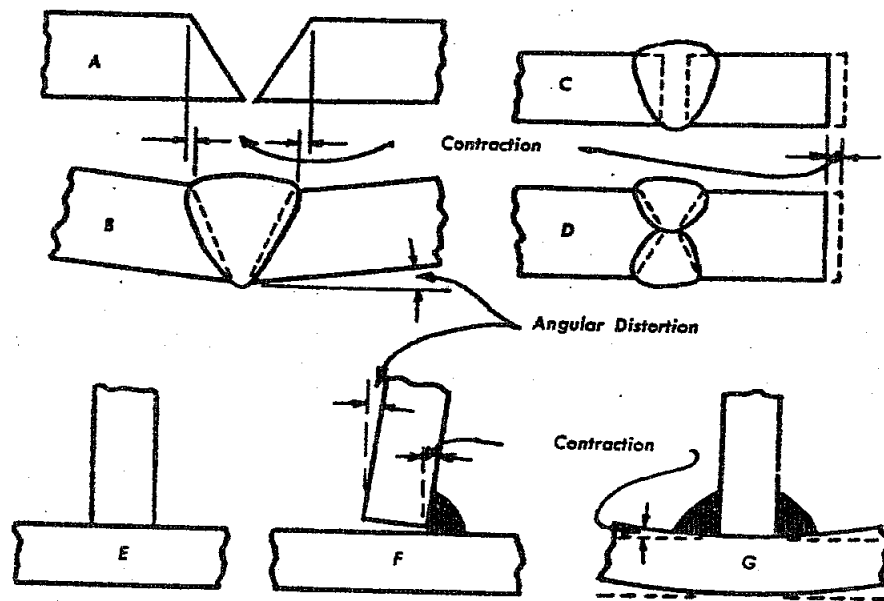


Fig. 3
Distortion of Butt and Fillet Joints due to Weld Metal Contraction

draw together can be found. The drawing may also be satisfactorily prevented by keeping a wedge X between the plates, 12 to 18 inches ahead of the welding (see Fig. 4B) or by separating the plates and making allowance for the contraction (see Fig. 4C). A spacing of approximately $\frac{1}{8}$ in. per linear foot of weld is found to be satisfactory for usual thicknesses. The exact amount, however, varies with different jobs and conditions.

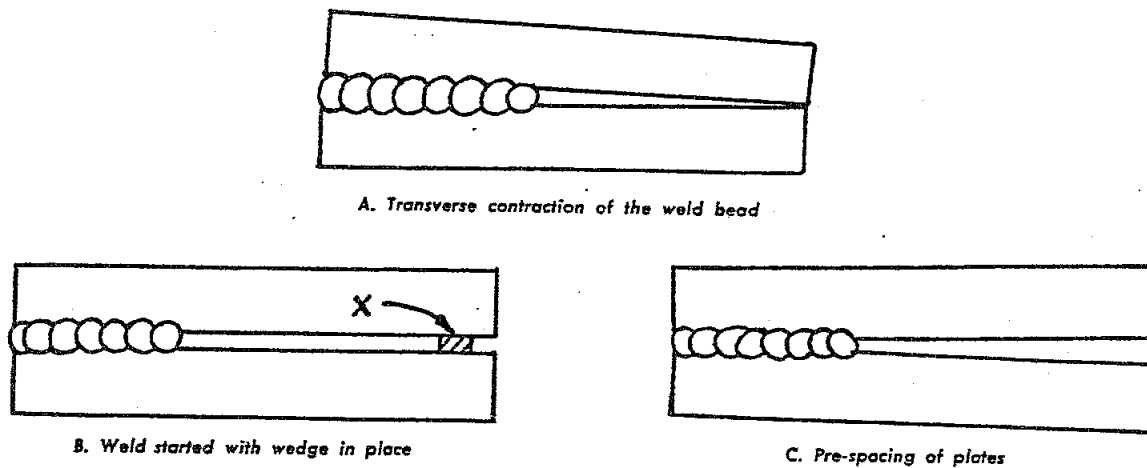


Fig. 4
Contraction of two butt-welded plates

Longitudinal Expansion and Contraction (Shrinkage)

When we consider movements along the joint the effect of expansion and contraction of the joint edges becomes important because these movements are resisted by the comparatively cool metal surrounding the weld point. Under this restraint considerable stress is set up in the metal.

This is illustrated diagrammatically in the sketches composing Fig. 5. With reference to A of Fig. 5, if we assume that a portion of one edge has been rapidly heated, the result is the production of an effect similar to that described in conjunction with Fig. 1B. In this case the expansion of the heated zone is prevented by the comparatively cool metal; the result is that the increased volume of metal in the heated zone is absorbed by a slight thickening or upsetting of the plate edge. Then, when cooling contraction takes place, the edge shortens, producing the shape shown in Fig. 5B. This is exactly what is happening to any joint edges or surface during welding, and the magnitude of the cooling effect depends upon the size of the heated zone in relation to the size of the plate.

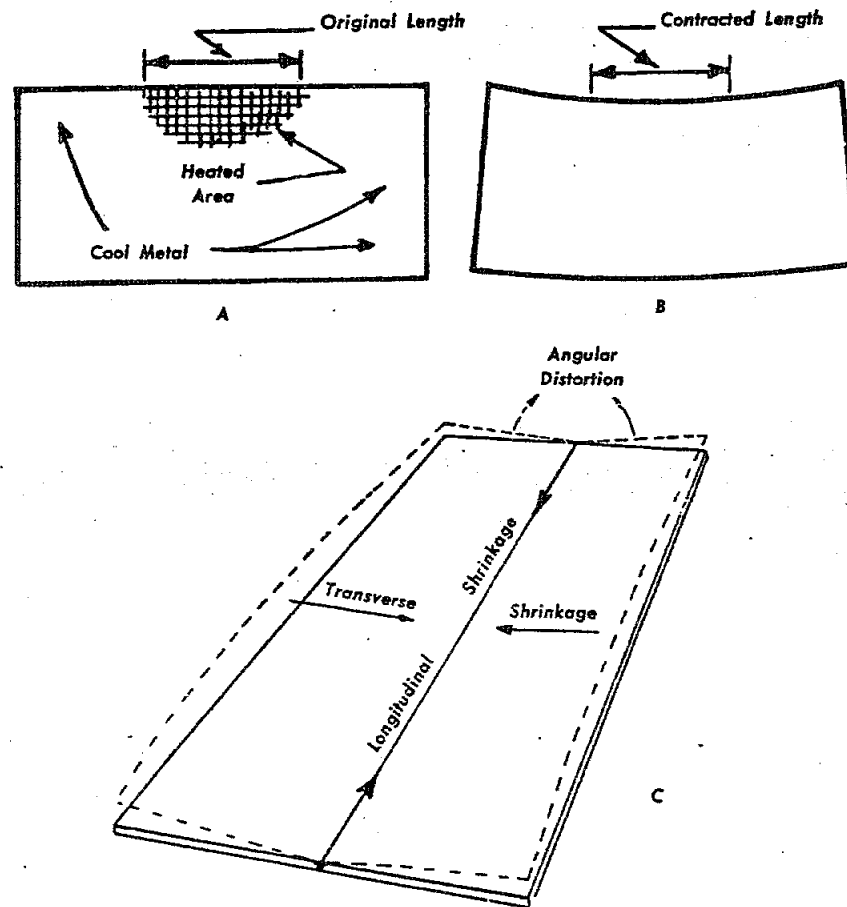


Fig. 5

A and B show how heating and cooling cause distortion of plate edge. C shows how contraction causes plates to take the shape shown by dotted lines

If the edges are restrained this effort to contract will, instead of causing distortion, set up stresses between the heated area (the weld) and the plate. This will happen if the parts being joined are massive and rigid or if rigidly clamped or rigidly tacked.

The effect of both the transverse and longitudinal contraction (shrinkage) of a butt joint where the plate is not rigid is shown in Fig. 5C. The important point which should be very clearly understood from the foregoing, is that local heating always produces

contraction during cooling of the base metal, which with the additional contraction of the weld metal, cause concave bending, i.e., shortening of the weld side of the joint both transversely and longitudinally.

Applying Principles to Practice

The foregoing principles may be advantageously applied to make welded joints in the following ways.

1. Multi-Pass Welds

In the examples just quoted, we have assumed that the required volume of weld metal is deposited in one pass. In practice, however, it is often necessary to complete the deposition in several passes. Generally speaking, multi-pass welding increases the angular distortion, i.e., a large number of small passes causes more distortion than a few large passes, the first pass forms a hinge point about which the contraction of subsequent passes takes place. Lateral shrinkage will also be greater because each pass will increase the number of upset areas along the plate edge. Therefore, the greater the number of passes the greater the distortion tendency.

In some cases, however, distortion in the longitudinal direction is a problem. The smaller the cross-section of a bead the less contraction force it can exert against the rigidity of the plates and the more it will stretch. In these cases, therefore, the number of passes should be increased rather than decreased. This apparently paradoxical relationship is a function of the thickness of the plate and its natural resistance to distortion. There is inherent rigidity against the longitudinal bending or shortening of a plate, providing the plate is thick enough. Light gauge sheets have little rigidity in this direction and, therefore, will buckle easily. Unless the two plates to be welded are restrained, there is virtually no lateral rigidity, since each of the two plates is free to move with relation to the other, so lateral distortion is more common.

2. Joint Design, Preparation and Fit-up

It has already been noted in reference to Fig. 3 that the more symmetrical the weld section and the more balanced the transverse contraction movements, the less will be the angular distortion. Joint design should, therefore, be as symmetrical as possible about the longitudinal centre line. Joint D of Fig. 3 is preferable from this viewpoint to B. Similarly a U groove preparation is better than a V groove.

Since the weld metal shrinkage is proportional to the amount of weld metal, it follows that the smaller the weld the better. It is therefore the duty of the designer to call for welds no greater than are required as determined by his strength calculations, and for the operator to make welds no greater than shown by the drawings.

A large fillet will give more angular distortion than a smaller fillet and a wide V groove more than a narrow groove since the contraction at the top will be greater (see Fig. 3).

Therefore V grooves should be designed for a minimum bevel, consistent with accessibility, and should be carefully prepared to see that this bevel is not exceeded.

3. Rate of Welding

The distortion of a joint will be affected by the rate of welding. As the arc travels along the joint the heat fans out in all directions from the weld point, as indicated in Fig. 6. Any heat which travels ahead of the weld point will distort the free joint edges and must, therefore, be kept to a minimum. The slower the rate of travel, the more time

there is for the heat to spread ahead of the weld point, as shown in A of Fig. 6, the faster the travel the less heat spread will be at and ahead of the weld point as shown in B.

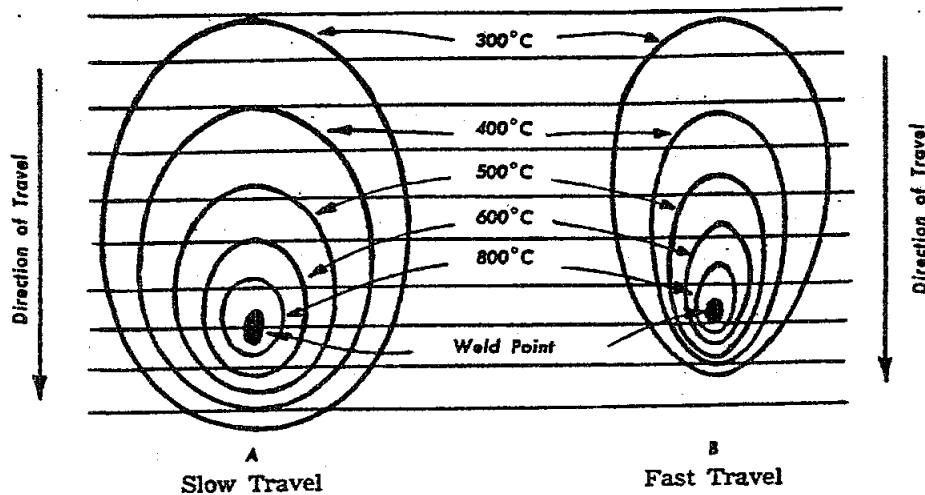


Fig. 6

4. Uniformity of Heat Input

Expansion and contraction of the metal in the heated zone is further complicated by the fact that the heat input to the joint is not uniform, but, as shown in Fig. 6 is in the form of a concentrated zone (the weld point) which travels along the joint as the weld progresses. At the weld point the heated joint edge is expanding and upsetting (as previously described) and the weld metal is deposited in the fully expanded condition. Behind the weld point the joint edges and weld metal are cooling and contracting. In front of the weld point the joint edges are relatively cold and not yet subjected to expansion.

Obviously a better effect could be secured if the heat could be applied to the joint uniformly and simultaneously throughout the whole length. Although this is not 100% possible, the welding procedures described later are intended to approach as near as possible to this ideal.

Conclusions

The lessons to be learned from the foregoing considerations are:

1. Joints should be designed to require a minimum amount of weld metal, e.g., a U groove is preferable to a V groove.
2. Joints should be uniform about the centre axis, e.g., a double V is preferable to a single V.
3. Joint size should not be greater than stress calculations indicate to be necessary.
4. Only the required amount of weld metal should be deposited.
5. The fewer the number of passes the less will be the angular and lateral distortion.
6. The rate of welding should be as fast as possible.
7. The heat input to the joint should be distributed as uniformly as possible.

Having discussed those factors which are fundamental in making welded joints, we will now describe the various procedures which may be adopted in order to minimize any undesirable or detrimental effects of expansion and contraction.

Mechanical Control of Distortion

Distortion may be partially or fully controlled by mechanical means, either by:

- (1) Pre-bending or setting.
- (2) Rigid clamping or fixing.
- (3) The counter action of equal and opposed welds, or similar weldments clamped or tacked together.
- (4) Sub-assembly.

As will be noted from Fig. 7, pre-bending or pre-setting can be applied to reducing (or eliminating) angular distortion of both butt and fillet welds.

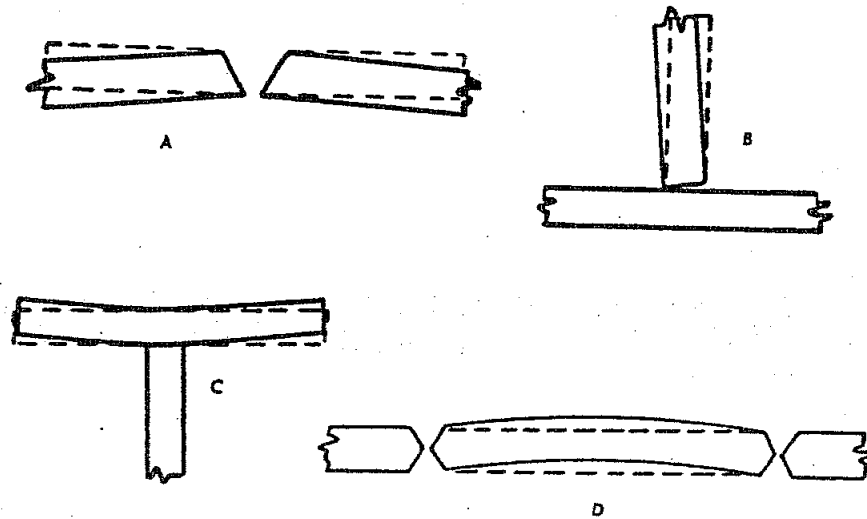


Fig. 7

Presetting of Joint Members to Allow for Contraction of Weld Metal

Alternatively, weldments may be rigidly clamped to heavy slabs or bases during the period of welding; also they may be mounted in rigid fixtures or assembled and rigidly tacked for welding. Strongbacks and temporary stiffeners may be used to align and rigidly maintain edges and joints.

Heavy slabs and fixtures will not only hold assemblies rigidly but will withdraw the heat of welding from the weldments, thus further reducing distortion. A similar effect can be obtained by immersing assemblies in water, or by spraying.

However, none of the methods of restraint can be expected to fully retain alignment. Some springing and distortion will usually follow release from such superimposed control.

Further, the greater the restraint against contraction the greater will be the residual stresses induced and the more the likelihood that cracking will result as in Fig. 2B.

Heavy weldments of heavy plate may in themselves offer great rigidity and restraint to welds.

Fig. 8 shows cover plates welded to H sections. The fillet welds will have a tendency to shorten due to their longitudinal contraction. This contraction will cause bending and a shortening of the sections. If they are tacked or clamped together as shown, this bending

tendency in each will be counteracted by the other. The procedure should be to start welding in short increments outward from the centre, alternating from one section to the other so that equal and opposite welds are made alternatively and thus counter-balance each other.

It is understandable that distortion will be increased in large assemblies where the welds are long. It therefore follows that if the job is broken down into a number of smaller weldments or sub-assemblies, the distortion in each will be less and can more easily be controlled and corrected. If necessary each sub-assembly can be straightened or machined before final fitting and welding. Therefore final fabrication from sub-assemblies is to be recommended and the designer should bear this requisite in mind. Sub-assemblies further make for easier and more efficient handling and reduce the accumulation of additive residual stresses.

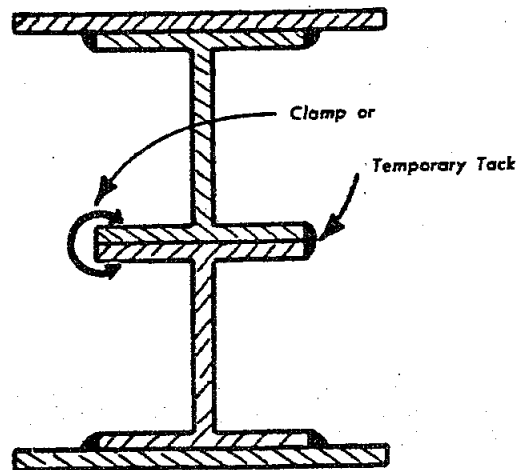


Fig. 8
Eliminating Distortion by Balancing Weld
Contractions of Two Similar Weldments Clamped or
Tacked Back to Back

Control by Welding Procedure

Experience has shown that control of distortion and a reduction of welded-in stresses can be obtained by carefully planning the welding procedure.

Seam Welds

The simplest form of distortion control is exemplified by the well-known method for welding a longitudinal seam of starting the weld some distance in from the end of the joint and making a short weld first, as shown in Fig. 9. In this way the first weld pre-sets the joint edges and prevents the closing in of the joint as the main weld proceeds (compare Fig. 4A).

It has already been mentioned that distortion control involves applying the proper pattern of heat distribution. We have seen how this principle may be applied by welding equal and opposite welds (see Fig. 8). Also it has been noted that it would be desirable to apply heat uniformly and simultaneously throughout the entire length of a joint. As this is obviously not possible in arc welding, the next best thing is to weld at spaced intervals along the joint.

Fig. 10 shows several sequences which apply this principle. A simple back-stepping method is shown at A. This consists of starting a weld a short distance from the end of a

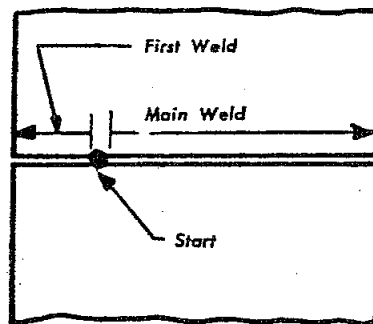


Fig. 9
Simple Welding Sequence

seam — the distance being the length of bead deposited by one electrode. The next weld is then started a similar distance from the first weld and is fused into the previous starting point, and so on, until the joint is completed. On long joints the welder works outwards from a central point as shown at B and C. This is an important principle to follow.

Still more elaborate variations of this procedure are the “staggered” or “wandering” sequence shown at D and E. These procedures consist of leaving spaces between each weld bead, progressing along the seam in this manner and then completing the unwelded spaces.

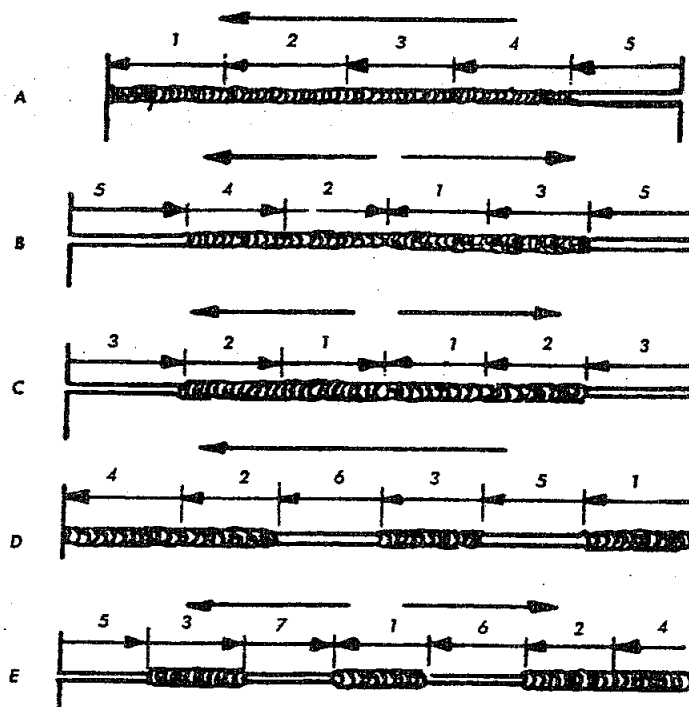


Fig. 10
Seam Welding Techniques.

Note: Long Arrows Indicate General Direction of Welding.
C Assumes Two Welders Employed.

This procedure may be used for both butt and Tee joints, but in the latter case the welds may be staggered on both sides of the joint as shown in Fig. 11.

Back-step and skip weld procedures (sequences) may also be used for multi-pass welds, as shown in Fig. 12.

With large areas of plating, the butts (i.e., the joints between ends of plates) should be welded before the seams (i.e., the joints between the long sides of plates). The gap should be set to allow for contraction by adjusting the free plate before welding.

The welding of seams should never be carried up to, or beyond, an unwelded butt, as the rigidity of the butt would then be too great. The seam should be terminated 12 to 15 inches short of the butt. The butt is then welded, after which the welding of the seam may be continued. This is illustrated in Fig. 13.

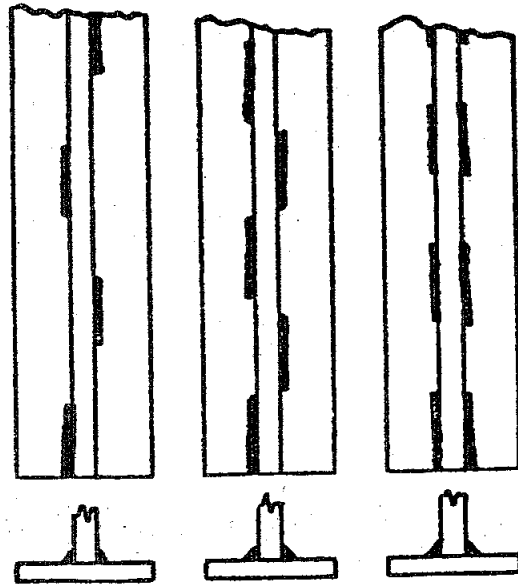


Fig. 11
Intermittent Fillet Welds

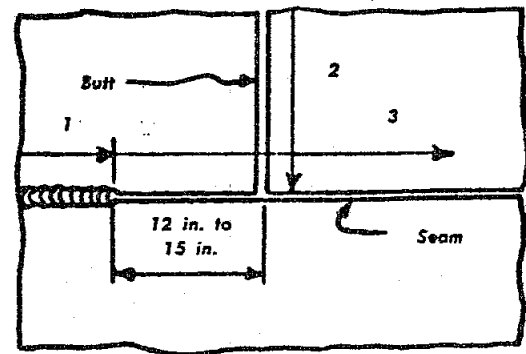


Fig. 13
Sequence for Seams & Butts

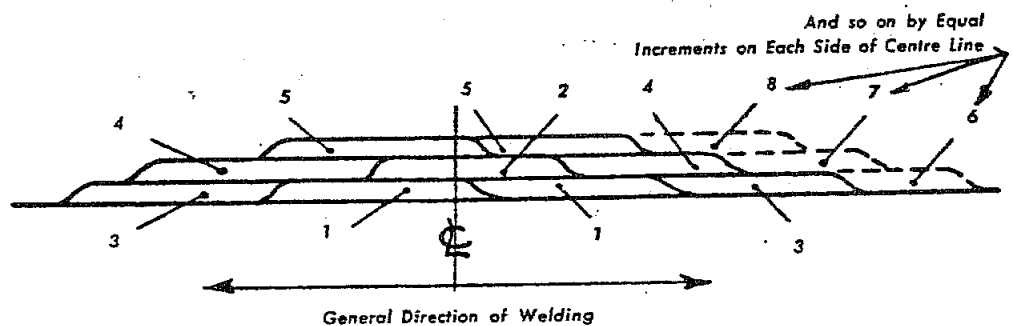


Fig. 12
Skip Procedure for Multi-Pass Welds

The welding should start at a central point and proceed outwards, keeping the progress or order of the welding more or less symmetrical about the centre, as shown in Fig. 14. In this way it is possible to arrange for each joint to have freedom of movement for the maximum period. Dark lines indicate completed welds and numbers indicate order of welds.

The sequence in which welds are carried out should be studied from the viewpoint of avoiding complete restraint which will inevitably introduce residual stresses in joints. This is exemplified by the recommended sequence shown for the assembly in Fig. 15.

Non-Continuous Fillet Welds

The main advantage of intermittent welding is that the heat input to the joint is considerably less and thereby distortion and stress are reduced.

It will, of course, be essential to make sure that a non-continuous weld will give the required joint strength. Quite often the minimum practicable size of fillet provides more strength than that required by design calculations; in such cases non-continuous welds may very well be used. On the other hand, if a complete joint seal is required, non-continuous welding cannot be adopted.

Another advantage is that the heat is more uniformly distributed than it would be in the case of a continuous weld. Moreover, the longitudinal weld shrinkage and, therefore, overall distortion, is only a small fraction of that produced by continuous welding. It has, in fact, been found that the reduction in these factors is far greater than would appear to be represented by the proportion of intermittent to continuous weld.

Combination of Plating and Stiffeners

Where plating and stiffeners are combined — as in ship bulkhead work — the butt and seam welds in plating should be welded before the stiffeners. The attachment of stiffeners should follow closely, but must never proceed beyond an unwelded plate butt or seam, otherwise the stiffeners will restrain the movement of the plate joints.

Similarly, joints in stiffeners should be welded before the stiffener is attached to the plating. A simplified example of the weld sequence for an application of this type is shown in Fig. 15.

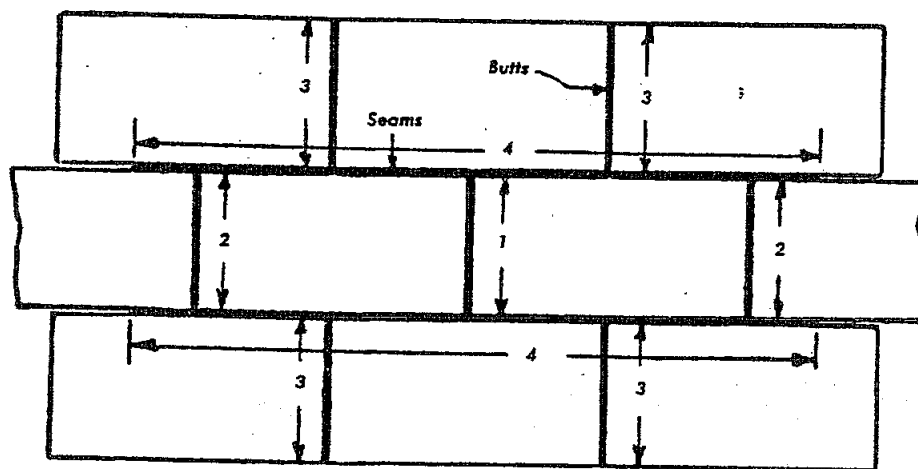
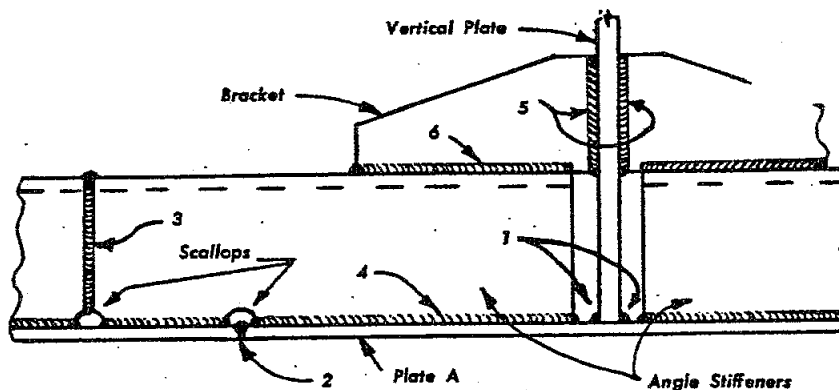


Fig. 14
Suggested Sequence for Plate Welding



- First step — weld transverse fillets; this allows plate A to shrink without restraint.
- Second — weld butts in plate A; plate is free to move.
- Third — butts in stiffener may now be welded while it is free to move.
- Fourth — stiffener may now be welded to plate.
- Fifth — brackets may be welded to vertical plate; bracket plate is free to move along stiffener.
- Sixth — bracket may now be welded to stiffener.

Fig. 15

An Example of Welding Sequence in a Structure Combining Plating and Stiffeners

Built-up Structures — Neutral Axis

The advantage of equal and opposite welding about a centre line has already been noted in Fig. 3, B and D and Fig. 8. Such a centre line is called the 'neutral axis' and is usually defined as the line on which there will be neither tension nor compression when the piece is flexed or bent.

In the case of a piece of plate the neutral axis coincides with the centre plane of the plate (see A, Fig. 16); similarly, in the case of an I beam or channel the neutral axis coincides with the centre of the web, see B and E. In the case of a Tee or angle section member, arranged as shown at C and D, the neutral axis is not in the centre of the depth, but is near the flange.

A clear understanding of the position and function of the neutral axis is necessary if the effects of welding either a plate or section, or a complete weldment are to be visualized.

As previously mentioned, the simple deposition of a bead of weld metal on the surface of a plate will cause that plate to bend with concavity on the welded side. This is simply due to the fact that the contraction of the weld metal exercises a shrinkage force which is offset from the neutral axis of the plate. If, on the other hand, beads were deposited simultaneously on opposite sides of the plate, the contractions of the two welds would be balanced about the neutral axis and there would be no bending.

This balancing of welds about the neutral axis of a built-up section or structure is a most important fundamental point in reducing distortion. A further example is shown in Fig. 17 where various welds are arranged around the neutral axis of a built-up section, the sequence in which the welds should be made being indicated by numbers.

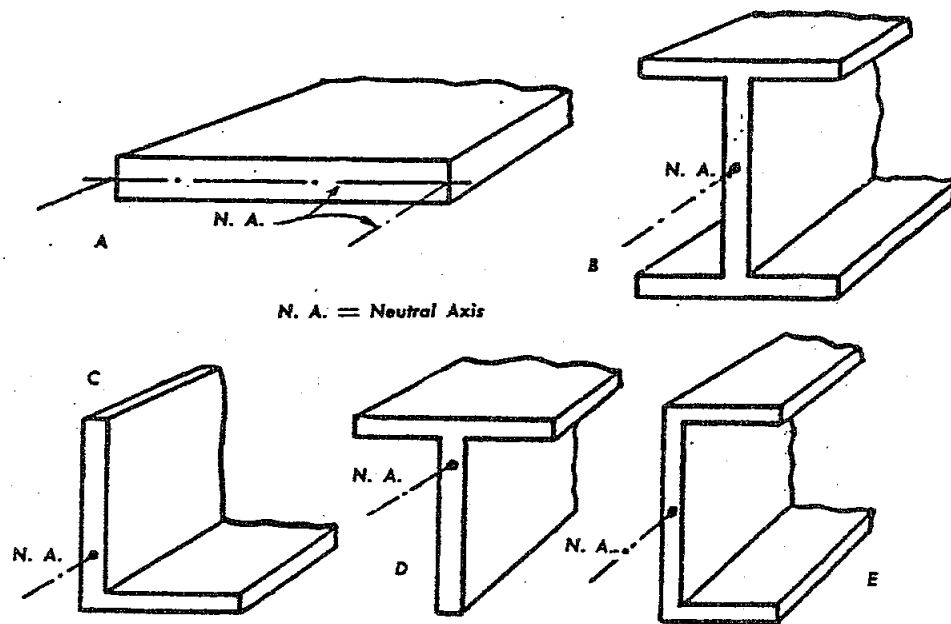


Fig. 16
Neutral Axis of Various Sections

Emphasis so far has been laid on the importance of welding equally about the neutral axis in order to maintain alignment. This assumes that the structure is true to begin with. In some cases this may not be so and welding unequally about the axis may be used as a means of straightening.

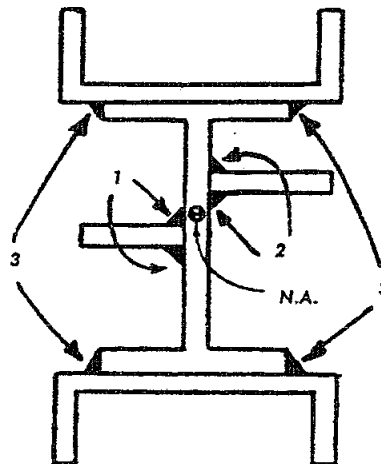


Fig. 17
Balancing the Sequences of Welds About the
Neutral Axis of a Section

A case in point is the construction of a beam from plate sections where the web plate has a curvature as received from the mill. This might be as much as $\frac{3}{8}$ inch in 5 feet. The following procedure may then be used to produce a straight beam. (See Fig. 18).

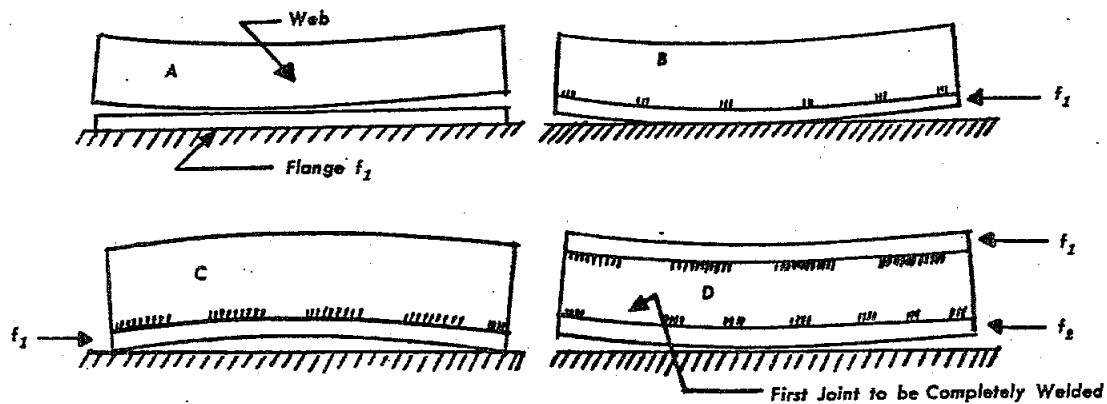


Fig. 18

Operations in Welding a Built-up I Beam with Curved Web

The flange plate f_1 is laid down on a slab and the web plate is set up vertically on it as in A. The flange is then pulled up to the web plate and strongly tacked as in B. The welding of this flange and the web is then carried on until the web is not only straightened but slightly bent in the opposite direction as shown in C. The second flange f_2 is now fitted to the web and tacked securely as in D. The welding is then completed, preferably using two welders on opposite sides of the web and working in the same direction. With such a sequence the beam should be reasonably straight on completion. Welding the first flange to the web before the second flange has been tacked to the latter results in a considerable bending effect due to the shortening of the weld inasmuch as the beam is not strong or stable without the second flange. If in doing such welding the beam is slightly 'over bent', the welding on the second flange, when completed, ought to be just sufficient to pull the beam back to the straight position, since due to greater rigidity the shrinkage effect will not be as great as under the conditions in which the first flange was welded.

Complicated Weldments—Accurate Assembly

In the case of complicated assemblies, the accuracy of preparing the various components requires careful consideration in order to enable dimensional tolerances to be kept to a minimum. An accumulation of tolerances over a number of components may create costly post welding difficulties. Obviously the more generous the tolerances the greater will be the fit-up gaps and an excessive amount of weld metal will be necessitated, resulting in greater distortion than would otherwise be involved.

To avoid this, it may be desirable to machine components to size in order to obtain close tolerances and increase the accuracy of the final weldment. It is also often possible to arrange the assembly of components in such a way that cumulative tolerances can be controlled and prevented from adversely affecting the final accuracy of the structure. (See Fig. 19)

Where accurate location points are essential, the assembly arrangement of the structure should provide for some allowance in case the various sub-assembly allowances do not work out to the degree of accuracy expected. For example, in the case of built-up I beams, the accumulated longitudinal contraction of the flange to web welds and the transverse contraction of the stiffener welds, will result in appreciable shortening of the beam, and it is usual to leave the flange and web plates overlength so that they may be finished to size after welding.

Similarly, for machine structures such as bedplates, engine frames, etc., those points which must be located to close tolerances, should be fixed only by the last weld which affects their location.

With tolerance of $+$ or $- 1/16$ inch on plates X and Y, assembly A would necessitate a tolerance of $+$ or $- 1/8$ inch, whereas the accuracy of B could be $+$ or $- 1/32$ inch.

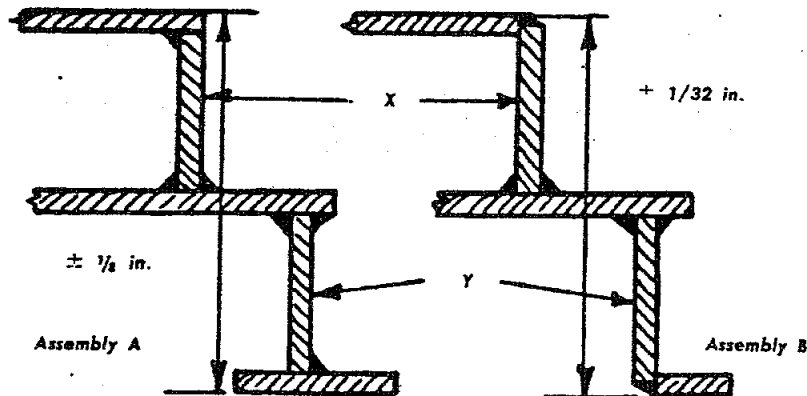


Fig. 19
Arranging Components to Ensure
Finished Accuracy

Peening

Reference has been made to peening as a method of controlling distortion. It does so by stretching the metal and promoting plastic flow. However, if peening is carried to excess, additional stresses can be set up and the metal made hard and brittle.

Peening is best carried out by a series of relatively light blows covering the surface of the weld as quickly and uniformly as possible. A round nosed tool with a diameter of $3/16$ inch or thereabouts used at an air pressure not in excess of 90 p.s.i. is desirable.

Since the effective depth of peening is usually not more than 1.8 inch, shallow thin welds of approximately this thickness lend themselves best to satisfactory peening. Each layer should be peened as it is deposited.

The operation of peening even when carried out carefully and with experience is bound to harden and flake the metal if distortion is to be appreciably reduced. This detrimental effect is eliminated however, by the heat effect of subsequent layers of weld metal. Therefore since the last pass of weld is not subject to re-heating, it is not advisable to peen this layer.

Shrinkage Allowances

It has already been noted that contraction or shrinkage depends on restraint and a number of other factors. It is difficult for any formula or table of allowances to take care of all such variations and any such information must be used with discretion and only as a basis for guidance. Actual measurements taken from similar or somewhat similar applications are far better employed.

However the following formulae taken from an article on "Shrinkage Distortion in Welding" appearing in the June 1950 issue of the Welding Research Supplement of the Journal of the American Welding Society (see Bibliography No. 1) will prove of value.

Butt Welds — Transverse Shrinkage

$$S = 0.18 \frac{A_w}{t} + 0.05d$$

where

S = Transverse shrinkage in inches,

A_w = Cross sectional area of welding in square inches,

t = Thickness of plate in inches,

d = Root opening, the free distance in inches between plate edges.

The formula is really applicable only for plate between $\frac{1}{4}$ inch and one inch in thickness. For thinner plate buckling may be a more important factor. For heavier plate a value of 0.20 should be substituted for 0.18.

Figures 21 and 22 give shrinkage allowances from another source for butt joints in a graphical form for ready reference. Figure 21 is for the usual 60° bevel preparation and Fig. 22 includes greater angles of bevel, which naturally produce greater shrinkage.

Butt Welds — Longitudinal Shrinkage

$$S = \frac{A_w}{A_r} \times 0.025$$

where

S = Longitudinal shrinkage in inches, per inch

A_w = Cross-sectional area of welding in square inches,

A_r = Cross-sectional area of restraining plates in square inches.

Fig. 20 illustrates these terms.

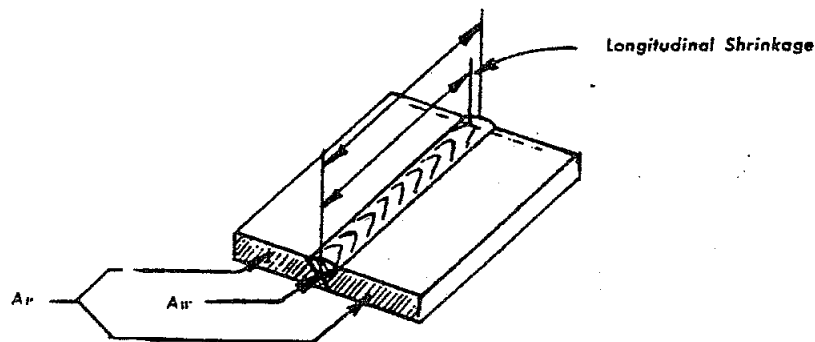


Fig. 20

Due to restraint this formula loses in accuracy if the cross-sectional area of the plates is greater than 20 times that of the weld. In such cases the chart shown in Fig. 23 may be used. It should be observed that in the curves in Fig. 23 the shrinkage, which attains high values for small resisting sections, falls extremely rapidly as the section increases. The shrinkage tends to become constant when the resisting section exceeds a

certain value. The form these curves take need not surprise us. In fact, the resistance to shrinkage offered by the resisting section increases very rapidly because the effect of shrinkage is a maximum in a relatively narrow band symmetrical with respect to the axis of the weld. Outside this band, only rather low temperatures are reached during welding and the metal offers a rapidly increasing resistance to the shrinkage arising from the hot parts. The resisting section, once it has exceeded slightly the section corresponding to the hot parts of the assembly, exerts essentially its maximum resistance. Further increase in resisting section has scarcely any effect on shrinkage.

The following observation makes this phenomenon more significant. When the cross-sectional area of the weld is increased, the highly heated transverse portion, which is acted upon by shrinkage, is larger, and the resisting section necessary completely to prevent the effects of shrinkage also is larger. This is what the curves show. The dotted curve in Fig. 23 shows the resisting section at which shrinkage becomes practically constant.

Fillet Welds—Transverse Shrinkage of a T Joint with Two Continuous Welds

$$\text{Shrinkage (S)} = \frac{\text{leg of fillet}}{\text{thickness of plate}} \times 0.04 \text{ inches}$$

For a double lap joint the multiplying factor should be 0.06 inches.

For plates 3/8 inch and under, buckling may be greater than shrinkage.

It has already been observed that joint design is a factor influencing shrinkage and others that should be noted are:

Preheating, because it provides more uniform heating and cooling.

Peening, because it stretches the weld metal.

The shrinkage due to submerged arc welding will usually be found to be about 1/2 that of manual welding.

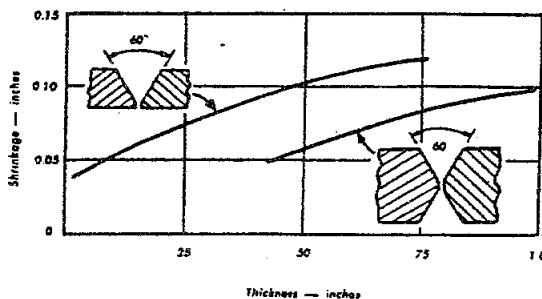


Fig. 21
Transverse Shrinkage of Single
& Double Vee Welds

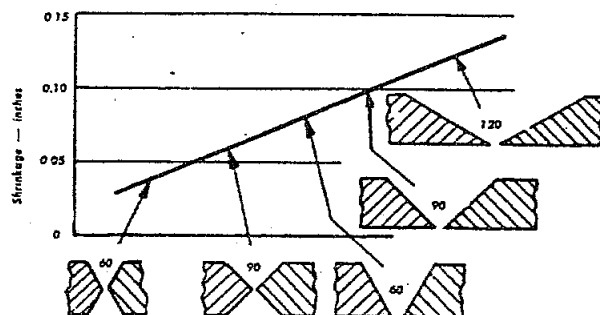


Fig. 22
Proportion of Transverse Weld Shrinkages
Produced by Various Types
of Butt Joint Preparations

Any degree of restraint may be expected to reduce the amount of shrinkage and such restraint may be applied in any of the following ways:

- (a) Clamping,
- (b) Rigid tacking,
- (c) Little or no root opening,
- (d) Cooling between passes.

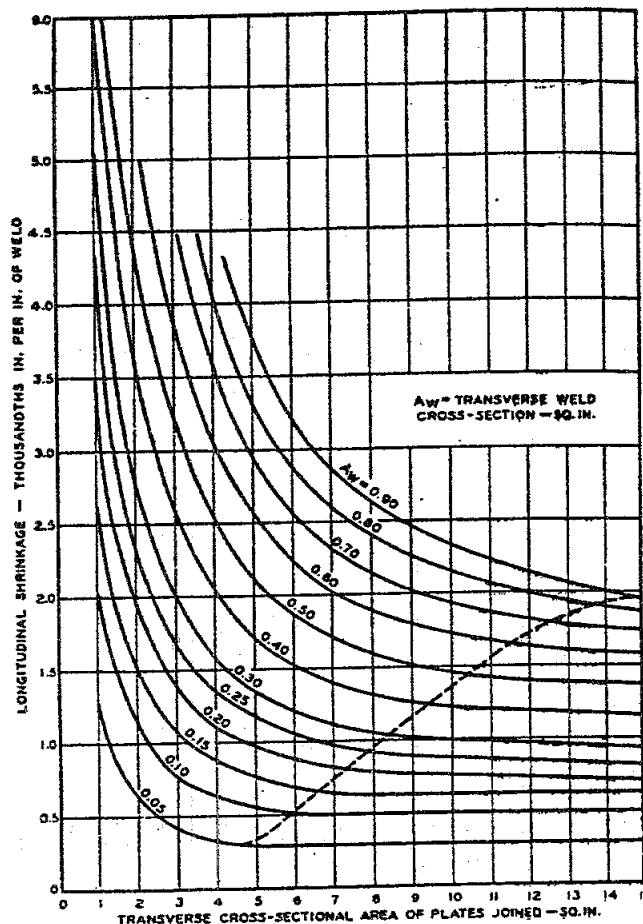


Fig. 23

Each curve represents the variation of unit longitudinal shrinkage as a function of the transverse cross-sectional area of the welded assembly for a given cross section. (The shrinkage tends to become stabilized when the sectional area of the assembly exceeds a certain value, which is indicated by the dotted line.)

This chart has been adapted from Guyot⁴

Angular Distortion

Unrestrained angular distortion as shown in B and F of Fig. 3 may amount to 10° or more but may be held very close to zero by presetting, bending, clamping, tacking and peening or by the use of a technique of alternately welding on either side of a joint.

Summarized Distortion Prevention Precautions READ

Summarizing the foregoing notes it will be seen that control may be exercised either by mechanical means or by organization of the welding procedure.

Mechanical control may be applied by:

- Presetting,
- The use of temporary stiffeners, clamps, heavy baseplates, strongbacks, special jigs and fixtures, back to back clamping or tacking,
- Artificial cooling.

Control by organization of welding procedure involves:

- Accurate preparation of the joint and close fit-up tolerances,
- The use of back-stepping or skip techniques,

- (c) Welding outwards from a central point,
- (d) Balancing welds on either side of a centre line or central point or around the neutral axis of a section,
- (e) Welding butts before fillets,
- (f) Using non-continuous welding (for fillets),
- (g) Arranging the weld sequence so that each joint has the maximum of freedom for the longest period,
- (h) Dividing a weldment into sub-assemblies.

In addition to the above procedures, which are aimed at reducing distortion, the following points should have attention since they are particularly concerned with the production of an accurate weldment:

- (a) Applying the welding so as to counteract plate edge curvature if any,
- (b) Arrange components so as to avoid accumulation of errors due to tolerances on plate width,
- (c) Where a high degree of overall accuracy is required, prepare components accurately in order to reduce fit-up tolerances,
- (d) Arrange the sequence of welding so that location points necessitating a high degree of accuracy are assembled and welded last,
- (e) Allow for weld metal shrinkage,
- (f) Arrange for some latitude in assembly dimensions so that a weldment can be machined to size if shrinkage and other allowances do not work out as expected.

Elimination of Distortion

Although the foregoing suggestions for minimizing distortion constitute a counsel of perfection it should be appreciated that, despite the observance of all reasonable precautions, some distortion may occur.

Any such distortion will however be less than it would have been had no precautions been taken and is usually readily rectified mechanically, e.g., by using presses, bulldozers, jacks, etc. Another way of correcting distortion is to use the contraction shrinkage method which makes use of the principle of resisted expansion and subsequent contraction on cooling.

For example, a piece of Tee section bent as shown at A, Fig. 24 could be straightened by heating and cooling the area XYZ. The basic principle which has already been studied is that the expansion of the metal in the heated zone is resisted by the cool surrounding metal. It therefore upsets and remains so on cooling resulting in a reduction in the distance XY, thus straightening the member as shown at B.

For the successful application of this principle both heating and cooling should be as rapid as possible and the dimensions of the heated area should be at a maximum where most contraction is desired. In the examples shown at A, C and D in Fig. 24 the tri-

angular area fulfills this condition, although large built-up I beams have been straightened by successively heating and cooling small round or rectangular areas along the convex side of the beam as shown at E. This principle can be applied also to the correction of distortion or buckling on plates or a combination of plating and stiffeners.

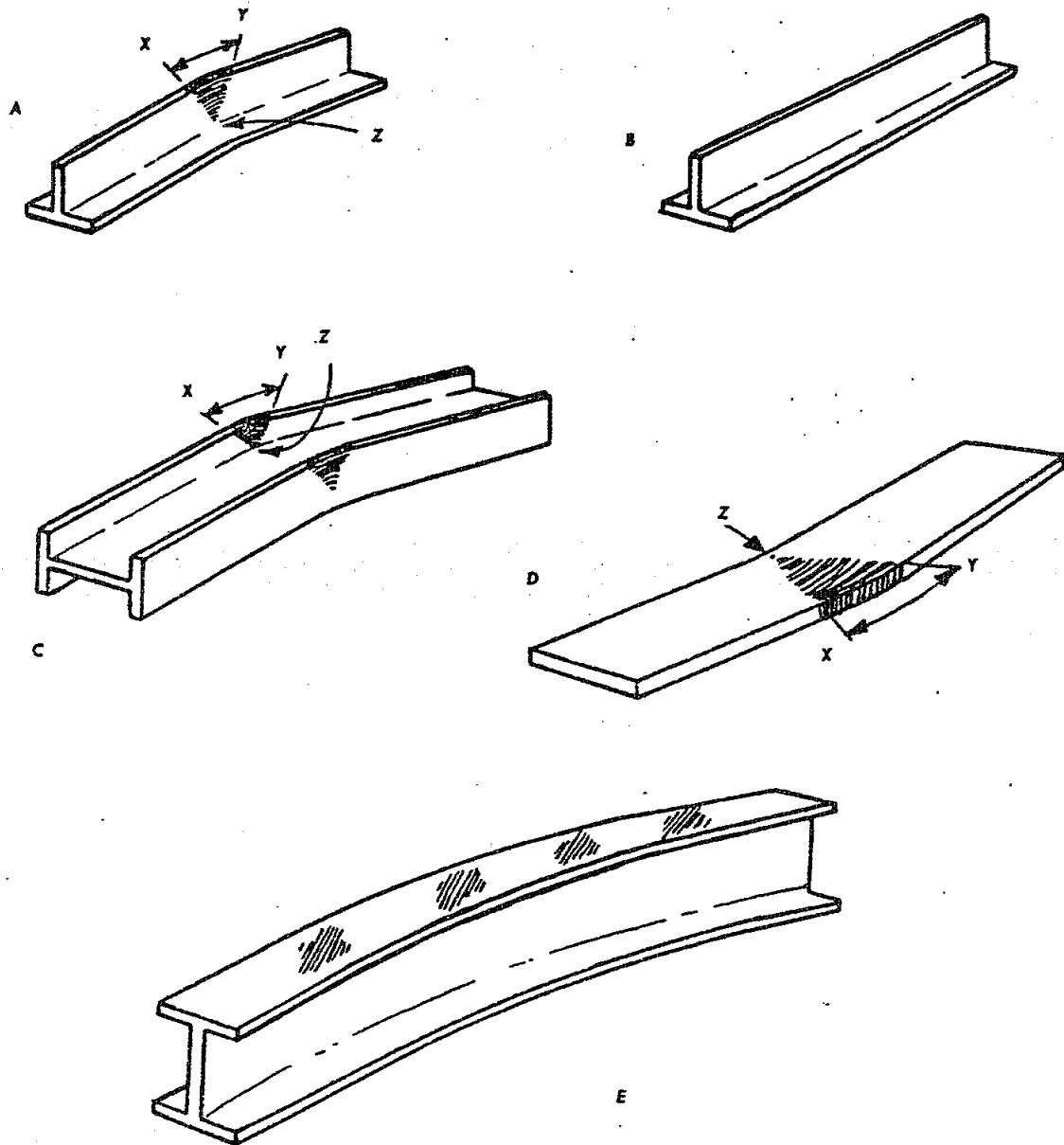
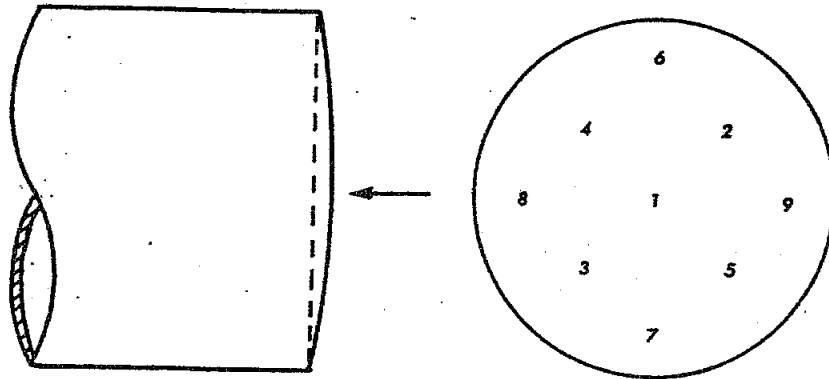


Fig. 24
Eliminating Distortion by Heating and Cooling

The following four examples illustrate the application of local heating for the elimination of buckling and distortion.



Heated spots should be as evenly spaced and symmetrical as possible, and in sequence shown by numbers. More or less spots may be required.

Fig. 25

Application of Heat in Local Spots,
Evenly Spaced and Symmetrical.
Omit 6-9 at first trial

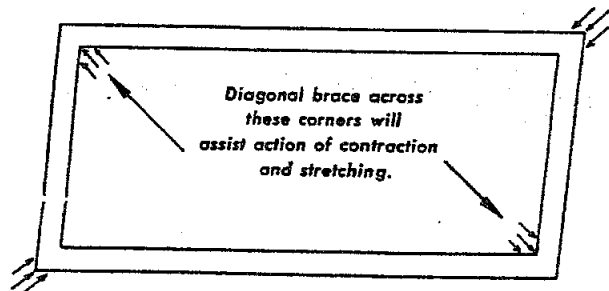


Fig. 26

Distorted Top Bar of Rectangular Tanks.
Apply heat to the corners of the flange

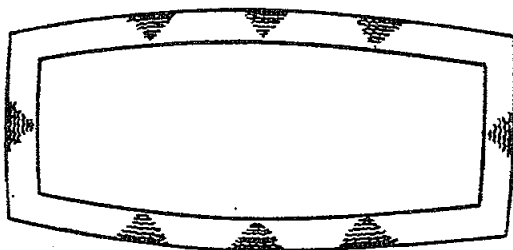


Fig. 27

Another Example of Distorted Flange
of a Large Rectangular Tank. Local
application of heat as shown

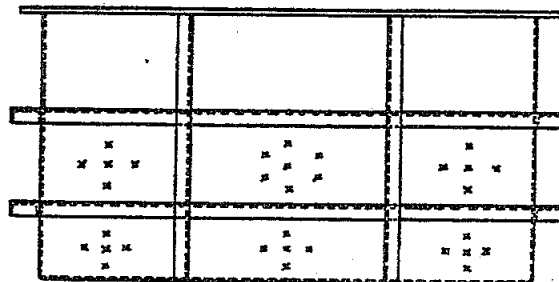


Fig. 28

Bulged Panels of a Rectangular Tank.
Apply heat to spots in the middle of
the Panels

The first example (Fig. 25) shows a simple cylindrical vessel with a flat welded end or bottom plate which may be in any thickness of plate usually encountered in what is called the light or medium tank work field. The weld is a corner weld inside and out round the periphery of the cylinder, which produces contractional stresses round the periphery of the flat end plate, thus causing a bulge in the centre. This condition can easily be corrected by application of heat in local spots as shown. To achieve the best result, the spots should be evenly spaced and symmetrical over the bottom. It must be noted that it is possible to overdo the application of local heat and undo much of the good which may have been done. Overheating can produce buckles as bad as those it is desired to eliminate. Therefore, in the first place, spots 1 to 5 should be tried, spots 6, 7, 8 and 9 being tried if the first prove inadequate. The heat should be applied in the form of spots about 2 inches in diameter and the plate brought to a cherry red colour. Care should be taken not to overheat or the effect can be nullified.

The heat, of course, is applied by means of an oxy-acetylene flame. In this connection a word or two about nozzle sizes may be helpful. A nozzle or tip for approximately 9 cubic feet per hour gas flow in a standard torch is the best for use for anything up to 5/8 inches thick plate. For thicker plates, a nozzle for approximately 23 cubic feet per hour gas flow in a heavy duty welding torch should be used.

Considerable trouble can be experienced with rectangular tanks and Fig. 26 shows diagrammatically the top welded bar on such a tank, indicating how the welding contractions have pulled it out of square. A simple way of correcting this is to apply heat to the corners of the flange as shown by the arrows, bringing the area heated evenly a few inches round the corners of the flange on the outside at the extremities of the long diagonal and round the inside of the flange at the extremities of the short diagonal. Correction can be assisted by inserting a prop, with a jack at one end, across the short diagonal and applying pressure to stretch. Alternatively, bars attached to either end of the long diagonal can be used with a turn buckle to draw in the tank in this direction. In some cases it may be necessary to torch cut the flange at each end of the long diagonal and possibly remove a triangular section to permit the necessary movement. Further assistance can be given in stretching the material by peening the metal adjacent to the welds down each corner of the tank. Care should be taken not to cause excessive indentations on the plate surface.

Another example (Fig. 27) of a large rectangular tank shows how the heavy type flange or curb can be distorted by the weld which joins it to the top of the tank body. Again the cure is comparatively simple; it consists of the local application of heat to the spots indicated by the arrows, and the heat in this case is applied across the face of the flange in a V shape, the wider part of the V being on the full side which is being shrunk. This is particularly necessary if the flange is a heavy one.

Large rectangular tanks with heavy stiffeners can bulge appreciably in the panels made by positioning of the stiffeners; this bulging can be eliminated by heat applied to spots in the middle of the panels as described previously. The sketch (Fig. 28) indicates the manner in which this can be done, and a tank in a comparatively bad state can be brought into good shape, with almost complete flatness in the panels.

Residual Welding Stresses

It has already been noted throughout this lesson that the heat from welding and the shrinkage of the weld metal sets up expansion and contraction which, if restrained, result in the creation of stress in the weld area. Stresses remaining in the metal when it has cooled are known as residual stresses in order to distinguish them from any stresses which may be created by the loading of the finished structure.

It may help students to understand the practical meaning and effect of stresses if they are regarded as internal compression or tensile forces in the metal. For example, a tensile stress develops across a butt weld when the weld is unable to contract normally. Usually these residual stresses are static and balanced, i.e., one stress is balanced by another and no movement results once this balance is attained.

To complete the picture of the stress situation it is also necessary to point out that due to the heat and work of rolling, some residual stresses may be present in plates and sections before any welding (or other work) is attempted. Normally these stresses are also in equilibrium; for example, each flange of an I beam probably incorporates residual rolling stresses but they are balanced by the equal and opposite stresses in the other flange.

However, when the balance of residual stresses is disturbed distortion may occur. As an additional example it may be mentioned that the application of heat to one flange of an I beam may cause distortion solely because the residual stresses in that flange are reduced; i.e., the balance of stresses is upset.

This is one reason why distortion sometimes occurs in a welded structure despite the use of every normal precaution.

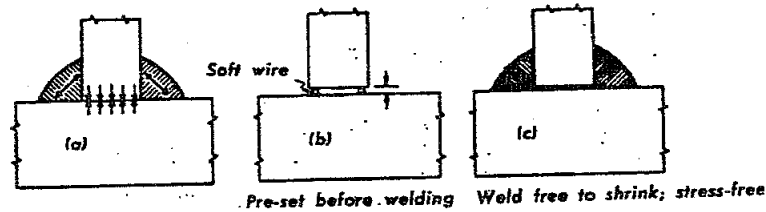
How Stresses May be Created and Prevented

The student will already be aware that if expansion and contraction are allowed to take place freely, little or no internal or residual stress is created. On the other hand if these movements, especially contraction, are resisted, such stresses are set up.

Almost invariably some stress is set up from welding. Completely free expansion and contraction is seldom if ever possible. Even if the parts being joined are readily free to move, longitudinal expansion of the welding edge is resisted by the cool metal surrounding the weld joint. Similarly, longitudinal contraction of the weld metal is resisted by the joint edges.

The transverse effects are, however, of greater magnitude and therefore more serious, particularly with regard to the contraction of weld metal. For example, if a weld is made between two rigidly fixed members contraction is impossible and a highly stressed condition results. The stress may in fact be sufficient to cause cracking in the weld area due to the inability of the weld or parent metals to stretch to the extent demanded by the contraction. From this we can learn that complete rigidity in the assembly of components for welding should be avoided. One of the two parts to be joined must remain free to move in order to allow transverse contraction of the weld if stresses are to be kept to a minimum.

The sketch at the left in Fig. 29 shows what happens when two heavy plates are welded together under restrained conditions. As the weld cools, it shrinks, but, since the plates are tightly butted, they cannot move relative to each other. Tensile stresses are, thus, developed in the weld. If these stresses exceed the tensile strength of the deposited weld, they will cause a crack in the weld. If the crack goes unnoticed, is covered by subsequent passes and gets through inspection without detection, it can act as a propagation source for fatigue failure in service. When welding heavy plate, it is good practice to space the members slightly before welding. In a joint where one member is resting on the other, as in Fig. 29, this can be accomplished by placing soft wires between the members. As the weld shrinks, the wires will be flattened, and the residual transverse stresses substantially reduced. Soft steel wire of 3/32" diameter or less, depending upon the volume of weld metal and consequent shrinkage, is usually used, although copper wire may be employed. In the latter case, care must be taken to keep the copper wire far enough away from the weld so that it does not melt and contaminate the weld metal.



In (a) there is no space between members, and tensile forces develop in the welds as they shrink. By setting the top member down on soft wires (b), movement is made possible, and the shrinkage forces are dissipated as they flatten the wires (c).

Fig. 29

It has been already noted that distortion may be reduced by fixing components either by tacking, clamping, or by assembling in jigs. Complete rigidity in this respect is however contrary to the above mentioned principle of minimizing stresses. Therefore unless weld metal can be permitted to contract freely, e.g., as in a preset joint, a balance must be found between the extremes of free movement and complete rigidity so that both distortion and stresses may be kept to a minimum.

Accurate edge preparation and joint fit-up has considerable influence on the production of stress-free joints. A variable and unnecessarily wide joint causes considerable heat concentrations at the wide places, thus creating excessive locked-up that is, residual stresses in the assembly.

Another preparation fault is excessive nose width, particularly if accompanied by a tight fitting joint. Not only is complete fusion of the joint difficult (if not impossible) to achieve but shrinkage of the deposited metal will be prevented. The result will be high shrinkage stresses which are very likely to cause cracking in service if indeed the weld does not crack before it is completed.

Rigid alignment and complete restraint of joints by strongbacks, clamps and such devices should be avoided. Fig. 30 shows several methods commonly used to align joints. In A the joint is made rigid and the method is entirely incorrect. In B and C the joint is free to contract and the methods are suitable while D is correct if the jack is removed after tacking and before final welding.

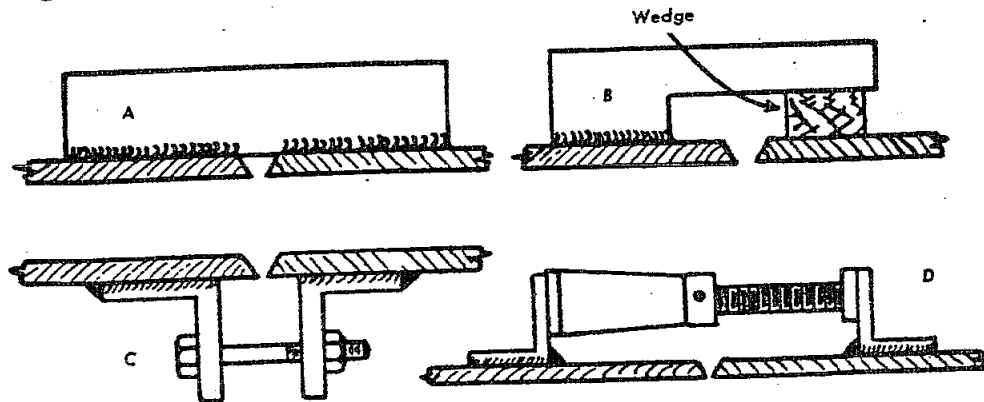


Fig. 30

With arrangement shown at
 A—Joint edges are not free to contract.
 B and C—Joint edges can contract freely.
 D—Jack must be removed after tacking.

It naturally follows that in structures combining rivetting and welding the latter should never be done after the rivetting which will make the weldment rigid. Welding should always precede rivetting. Where welding must be done in close proximity to an already rivetted joint a number of rivets should be removed to ensure that the weld contraction will not be restrained.

It can be generally assumed that residual stresses have no influence on the ultimate strength of a given member, if the material is in the ductile state and works under static or impact loading.

The same may be said of fatigue loading if no notches are present. However, every effort should be made to control residual stresses especially under the following conditions:

1. Use of brittle and notch sensitive steels;
2. Low temperatures;
3. Abrupt change of section in design;
4. Undercutting and nicking.

Stresses in Thick Welds

High residual stresses, with the possibility of stress cracking, are most likely to occur when welding thick material due to the increased cooling effect of the mass of metal which, with the greater carbon content usually associated with thick material, increases the brittleness of the weld.

In order to overcome these undesirable features, it may be advisable to preheat, particularly in cold weather. Moreover, the weld should always be allowed to cool as slowly as possible and where the welding conditions or atmospheric temperature tend to promote rapid cooling, postheating may also be desirable.

Stresses caused by restraint of weld contraction due to the weight of heavy parts may be avoided by mounting the components on rollers in order to provide easy movement.

Another problem is the possibility of excessive stresses being set up in the initial bead or beads of a multi-pass weld or in a partially completed weld before it has gained its complete strength to resist. The remedy is to build up as rapidly as possible a mass of weld metal, which will withstand the local contraction stresses.

This can be done by adopting the block or cascade method of welding which entails the rapid building up of short weld lengths to the complete, or nearly complete section of the joint. In this way ample weld strength to deal with the stresses is assured by the time these stresses begin to act in full, due to contraction. The order of depositing the sections may follow the back-step procedure or a skip or wandering procedure may be used, but each section is built up continuously once started so that a relatively large amount of heat is put into the plate adjacent to each section and there is consequently no risk of chilling due to a rapid fall in temperature. Such a procedure may be particularly necessary with thick alloy steels containing hardenable elements.

The contour of the block or cascade technique is as shown in Fig. 12 illustrating the skip procedure. This can be achieved by overlap of beads or by making each bead slightly shorter than the previous bead. Tapered in this way each block can be subsequently joined quite easily to succeeding ones.

A thick bead with concentrated heat can be readily deposited vertically and this is

another technique of accomplishing the same result as in block welding.

Any convex bead will resist cracking better than one of flat or concave contour and can therefore be used to advantage when rigidity may produce cracking.

Peening

Peening has already been reviewed as a means of reducing distortion. It may also be used to prevent cracking in regions of very high restraint.

Heat treatment, aging and mechanical stretching are recognized as other means of stress relieving, thereby reducing the chances of cracking.

Summary on Stresses

Summarizing the foregoing notes on stresses, their cause, prevention and relief, the following are the main points to be borne in mind:

1. Stresses may be the result of heating and rolling plates and sections during manufacture or they may result from welding heat or heat purposely applied for straightening or bending purposes.
2. Stresses result from resisted expansion and contraction.
3. Avoid complete rigidity of assembly. Do not use immovable strong-backs or clamps or rigid tacking.
4. Avoid rigidity due to rivetting before welding.
5. Carefully and accurately prepare and fit up joints.
6. Avoid rigid joints.
7. Use extra precautions such as preheating, postheating and block welding on thick material and particularly on low alloy and notch sensitive steels.
8. Avoid welding at low temperature.
9. Avoid abrupt changes of sections in design, or nicking and undercutting in welding.
10. Avoid small stringer beads.
11. Allow welds to cool slowly.
12. Peen or heat treat if necessary.
13. Weld vertically up to build a thick weld section and induce more heat for slower cooling.

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GUIDES AND EXERCISES

MODULE 7

WELDING DISTORTION

AND

RESIDUAL STRESSES

WELDING DISTORTION AND RESIDUAL STRESSES

MODULE 7

Guides & Exercises

To obtain maximum benefit from this module we suggest that you follow this guide and complete the exercises as indicated. It is important that you work through the text methodically, studying each section thoroughly before moving on. The exercises are designed to give you an indication of whether you have learned the material and can move on or whether you need to go back and study the section again.

Do the exercises honestly. They will not help you unless you take them seriously. If you get a question wrong go back through the text until you understand where you have gone wrong and know the correct answer.

The length of time required to complete the module will vary from student to student. Find your own pace. Do not rush. Remember you are trying to teach yourself something, not win a race.

Some people like to underline sections when they read a text. We suggest that you use caution if you do this. What you think is important first time you read it may be different after reading it three times. We suggest you read a section three times thoroughly before highlighting anything.

The last exercise is designed to give you an indication of whether you are ready to take the WIC closed-book exams. The exercise questions are of a similar standard to the official exams. Do not take the exam until you feel you are ready and you may wish to study several Modules before taking the exams on each. The details of the examination procedures are on a separate sheet.

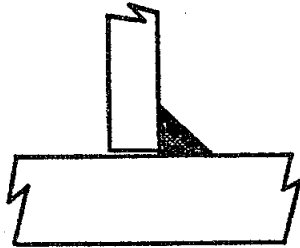
If you have any difficulties with this Module do not hesitate to ask for help. You may find you learn more by attending some of the seminars and you should also contact your local WIC Chapter to see if they can be of assistance. Remember, if you fail the examination you can always try again later.

MODULE 7

Guide 1

Carefully read pages 1 to 6 and answer the following questions:

1. Describe or sketch what happens when a bar is gripped at both ends so that neither expansion nor contraction is allowed to take place, and heat is applied.
2. A fillet weld is placed as per the sketch.



Draw a sketch to denote how angular distortion would affect component.

3. True or False?

Weld metal shrinkage is not proportional to the amount of weld metal.

Check your answers for accuracy. If any of your answers are wrong re-study the guide subject matter until you understand it.

MODULE 7

Guide 2

Carefully read pages 7 to 12 and answer the following questions:

1. Distortion may be partially or fully controlled by mechanical means by: (select the correct statements)
 - (a) Rigid clamping or fixing
 - (b) Pre-bending or setting
 - (c) Pre-weld heat treatment
 - (d) Post-weld heat treatment
 - (e) Sub-assembly

2. In seam welding what is the simplest form of distortion control?

3. True or False?

Where plating and stiffeners are combined as in ship bulkhead work, the butt and seam welds in plating should be welded before the stiffeners.

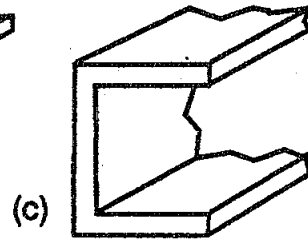
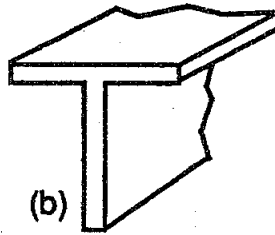
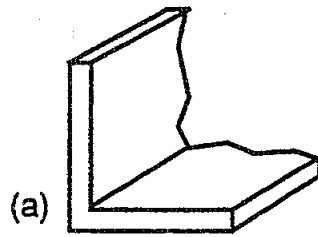
Check your answers for accuracy. If any of your answers are wrong re-study the guide subject matter until you understand it.

MODULE 7

Guide 3

Carefully read pages 13 to 20 and answer the following questions:

1. Show the position of the neutral axis in the following sections:



2. What is the following formula applied to?

$$S = 0.18 \frac{Aw}{c} + 0.05d$$

3. What is the following formula applied to?

$$S = \frac{Aw}{A_p} \times 0.025$$

Check your answers for accuracy. If any of your answers are wrong re-study the guide subject matter until you understand it.

MODULE 7

Guide 4

Carefully read pages 21 to 27 and answer the following questions:

1. Which contraction effects in the weld metal are of the greater magnitude and, therefore, are more serious?
 - a) Longitudinal
 - b) Transverse
2. Is rigid alignment and complete joint restraint by strong backs, clamps and similar devices a recommended practice?
3. Is the following a true statement?

Any convex bead will resist cracking better than one which is flat or has a concave contour.

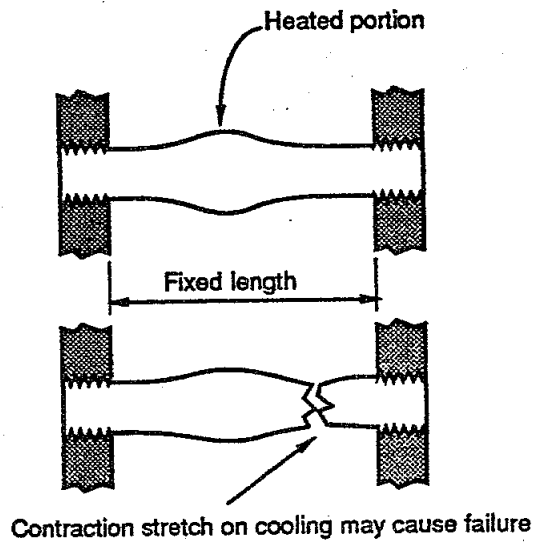
Check your answers for accuracy. If any of your answers are wrong re-study the guide subject matter until you understand it.

MODULE 7

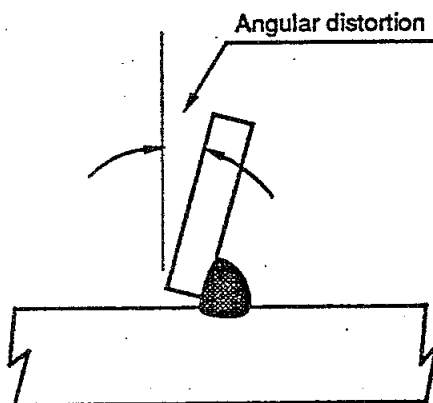
ANSWERS

Guide 1

1. (a) Causes upsetting
(b) Upsetting remains on cooling and bar stretches or:



2.



3. False

MODULE 7

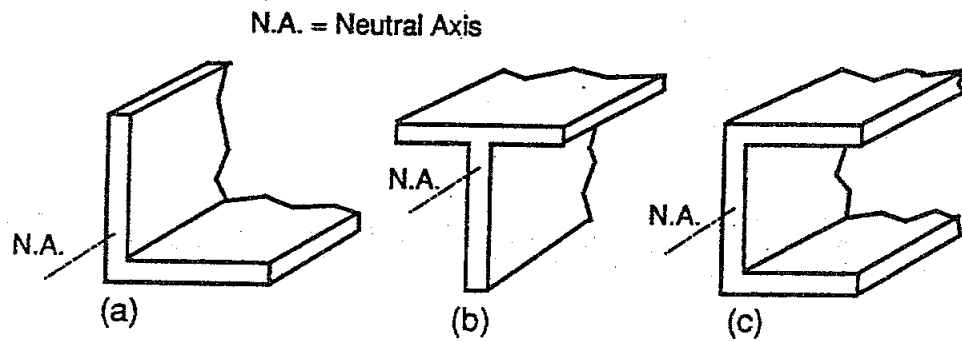
ANSWERS continued

Guide 2

1. (a) (b) (e)
2. Start the weld some distance in from the end of the joint, making a short weld first.
3. True

Guide 3

1.



2. Transverse shrinkage - butt welds
3. Longitudinal shrinkage - butt welds

Guide 4

1. (b) transverse
2. No
3. Yes

MODULE 7

TEST

This test is designed to determine whether you are ready to attempt the formal examination.

Complete the ANSWER SHEET and compare the results with the TEST KEY. If you have a pass mark less than 70% you are advised to re-study the material.

1. Which of the following statements is correct ?

- (a) Expansion and contraction are proportional to the dimensions of the heated area
- (b) When a bar is heated under restraint, its stress relieves itself as it cools
- (c) Slow cooling of a heated area will provide the greatest amount of shrinkage
- (d) Heating an area of plate will cause stretching as it cools
- (e) When the metal is heated, it expands, but it does not shrink back to its original size when it cools

2. To reduce the amount of angular distortion you should:

- (a) increase the travel speed
- (b) reduce the angle of the preparation
- (c) preheat the metal
- (d) all of the above
- (e) none of the above

3. When a structural member has been bent sharply, it can be straightened by:

- (a) heating a V shaped section of the web underneath the bent area of the flange
- (b) heating the inside corner of an angle, channel, I beam or T bar
- (c) heating a V shaped area at the point of the greatest bend, with the top of the V at the point of greatest bend
- (d) heating all along the edge of the section
- (e) heating all along the edge opposite to the one which is bent

MODULE 7

TEST continued

4. Of the many mechanical means of controlling distortion, which of the following will have the least residual stress?
- (a) rigid clamping
 - (b) subassembly of the sections
 - (c) heavy strongbacks, welded on both sides of the joint
 - (d) similar weldments clamped back to back
 - (e) preset the plates about 5 degrees away from the face of the weld
5. Decreasing the number of weld beads in a specific weld will:
- (a) result in annealing the weld area
 - (b) give a finer grain structure
 - (c) reduce the transverse shrinkage
 - (d) increase the transverse shrinkage
 - (e) possibly crack the root pass
6. The neutral axis is:
- (a) the line on which there will be neither tension or compression when the piece is flexed or bent
 - (b) the center line of a weld bead halfway between the root pass and the face pass
 - (c) the outside center line of the web of a channel
 - (d) the inside corner line of an unequal legged steel angle
 - (e) the dimensional halfway point of a welded assembly
7. When expansion and contraction are prevented, heating and cooling will cause:
- (a) no residual stresses
 - (b) failure due to lamellar tearing
 - (c) no permanent deformation or failure
 - (d) failure, when metal is highly ductile
 - (e) failure when the metal is not sufficiently ductile

MODULE 7

TEST continued

8. When heated, unrestrained metal will expand:
- (a) transversely (across the weld)
 - (b) volumetrically (in all directions)
 - (c) until it upsets
 - (d) longitudinally (lengthwise)
 - (e) most, across the width of the weld
9. Which of the following statements about peening is INCORRECT?
- (a) It should not be used on the last pass
 - (b) It puts the surface of the weld in compression
 - (c) It should not be used on root passes
 - (d) It can be used to form the surface contour of the weld to the inspector's satisfaction
 - (e) It should be stopped before the weld surface starts to flake
10. To avoid longitudinal warping of a plate when it is being cut to width, you would:
- (a) cool the outer edge with an air blast
 - (b) cut both edges at the same time
 - (c) dog the plate down to the cutting table
 - (d) prebend the plate away from the cut
 - (e) slow down the cutting speed

G12

Canadian Welding Bureau Answer Sheet - Module 7

Complete the "Answer Sheet" and compare the results with the "Test Key". If you have a pass mark less than 70%, you are advised to re-study the material.

Please circle only ONE letter corresponding to the answer you think is most correct.

QUESTION	ANSWERS				
1	a	b	c	d	e
2	a	b	c	d	e
3	a	b	c	d	e
4	a	b	c	d	e
5	a	b	c	d	e
6	a	b	c	d	e
7	a	b	c	d	e
8	a	b	c	d	e
9	a	b	c	d	e
10	a	b	c	d	e

The answer key below is provided for your use in the event that you wish to retest yourself.

QUESTION	ANSWERS				
1	a	b	c	d	e
2	a	b	c	d	e
3	a	b	c	d	e
4	a	b	c	d	e
5	a	b	c	d	e
6	a	b	c	d	e
7	a	b	c	d	e
8	a	b	c	d	e
9	a	b	c	d	e
10	a	b	c	d	e

Canadian Welding Bureau
Test Key - Module 7

Compare your answer sheet to this key.

QUESTION	ANSWERS				
1	☒ a	b	c	d	e
2	a	b	c	☒ d	e
3	a	b	☒ c	d	e
4	a	b	c	d	☒ e
5	a	b	☒ c	d	e
6	☒ a	b	c	d	e
7	a	b	c	d	☒ e
8	a	☒ b	c	d	e
9	a	b	c	☒ d	e
10	a	☒ b	c	d	e