UNIT 12 RESIDUAL STRESSES, DISTORTION & WELD DEFECTS

Structure

12.1 INTRODUCTION

In the previous unit we have studied various methods of welding. In all the mentioned methods one thing is common that is the requirement of heat source. It is also known that when a piece of metal is heated, the metal expands. Upon cooling, the metal contracts and tries to resume its original shape. These expansion and contraction forces act on the weld metal and base metal of a welded joint; however, when two pieces of metal are welded together, expansion and contraction may not be uniform throughout all parts of the metal. This is due to the difference in the temperature from the actual weld joint out to the edges of the joint. This difference in temperature leads to internal stresses, distortion, and warpage.

All metals, when exposed to heat build-up during welding, expand in the direction of least resistance. Conversely, when the metal cools, it contracts by the same amount; therefore, if you want to prevent or reduce the distortion of the weldment, you have to use some method to overcome the effects of heating and cooling.

In this unit, we are going to study the various reasons for these stresses and distortion. We will also go through the factors affecting distortion and the methods to control it. Distortion is one of the major defects while welding but there are other important defects, which should be studied as they occur very often while welding. The causes of defects and their remedies are discussed briefly in this unit.

Objectives

After studying this unit, you should be able to know

- the causes of stresses and distortion,
- various factors affecting distortion,
- various method to control the distortion, and
- various types of defects which can be caused during welding.

12.2 RESIDUAL STRESSES AND DISTORTION

The temperature distribution in the weldment is not uniform as a result of local heating (by most welding processes), and changes that take place as welding progresses. Heat-affected zones of weld and the base metal immediately adjacent to the welded area are at a temperature substantially above that of the unaffected base metal. As the molten pool solidifies and shrinks, it begins to exert shrinkage stresses on the surrounding weld metal and heat-affected zone. Compressive stresses are created in the surrounding cold parent metal, when the weld pool is formed due to the thermal expansion of the hot metal (heat affected zone) adjacent to the weld pool. However, tensile stresses occur on cooling when the contraction of the weld metal and the immediate heat affected zone is resisted by the bulk of the cold parent metal.

This can be explained with an example, while welding a single-V butt joint (Figure 12.1(a)), the highest temperature is at the surface of the molten puddle. The temperature decreases as you move toward the root of the weld and away from the weld. Expansion and contraction are most prominent where the temperature of the molten metal is the highest. Warpage or distortion starts as the weld begins to cool, this is due to the contraction of the surface of the weld joint. Figure 12.1(b) shows how the same principles apply to a tee joint. Figures 12.1(c) shows the distortion caused by welding a bead on one side of a plate while Figure 12.1(d) shows distortion caused by welding two plates together without proper tack welds.

Figure 12.1 : Distortion Caused by Welding

(Courtesy: http://www.sweethaven.com/academic/lessons/021100/00/lessonmain.asp?lesNum=3&modNum=5)

Residual stresses in weldments have following two major effects : First, they produce distortion. Distortion is caused when the heated weld region contracts non-uniformly, causing shrinkage in one part of the weld to exert eccentric forces on the weld cross-section. The weldment strains elastically in response to these stresses. The distortion may appear in butt joints both as longitudinal and transverse shrinkage (as shown in Figure 12.2(a), and as angular change (rotation) when the face of the weld shrinks more than the root. The latter change produces transverse bending in the plates along the weld length. These effects are shown in Figure 12.2(b). Distortion in fillet welds is similar to that in butt welds. Transverse and longitudinal shrinkage as well as angular distortion results from the unbalanced nature of the stresses in these welds (Figure12.2(c) & (d). Since fillet welds are often used in combination with other welds in a weldment, the specific resulting distortion may be complex.

Secondly, residual stresses may be the cause of premature failure in weldments. If the stresses generated from thermal expansion/contraction exceed the yield strength of the parent metal, localised plastic deformation of the metal occurs. Plastic deformation causes a permanent reduction in the component dimensions and distorts the structure.

There are mainly six types of distortion :

Longitudinal and Transverse Shrinkage

Twisting Contraction of the weld area on cooling results in both transverse and longitudinal shrinkage, whereas non-uniform contraction (through thickness) produces *angular distortion*. For example, in a single V butt weld, the first weld run produces longitudinal and transverse shrinkage and rotation. The second run causes the plates to rotate using the first weld deposit as a fulcrum. Hence, balanced welding in a double side V butt joint can be used to produce uniform contraction and prevent angular distortion. Similarly, in a single side fillet weld, non-uniform contraction produces angular distortion of the upstanding leg. Double side fillet welds can therefore be used to control distortion in the upstanding fillet but because the weld is only deposited on one side of the base plate, angular distortion will now be produced in the plate.

Figure 12.2 : Stresses in Welds

Bowing and Dishing

Longitudinal bowing in welded plates happens when the weld centre is not coincident with the neutral axis of the section so that longitudinal shrinkage in the welds bends the section into a curved shape. Clad plate tends to bow in two directions due to longitudinal and transverse shrinkage of the cladding; this produces a dished shape. Dishing is also produced in stiffened plates. Plates usually dish inwards between the stiffeners, because of the angular distortion at the stiffener attachment welds.

Buckling

Long-range compressive stresses can cause elastic buckling in thin plates. This resulting in dishing, bowing or rippling. Distortion due to elastic buckling is unstable, i.e. if you attempt to flatten a buckled plate, it will probably "snap" through and dish out in the opposite direction.

Twisting

This is caused by shear deformation at the corner joints. Unequal longitudinal thermal expansion of the abutting edges causes twisting. Increase in number of tack welds can help in reducing shear deformation and hence amount of twisting.

Figure 12.3 : Twisting Due to Shear

12.3 FACTORS AFFECTING DISTORTION

As discussed in the previous sections if a metal is uniformly heated and cooled there would be almost no distortion. However, in welding the material is locally heated and restrained by the surrounding cold metal, stresses are generated higher than the material yield stress causing permanent distortion. The principal factors affecting the type and degree of distortion are described below :

Parent Material Properties

Parent material properties which influence distortion are coefficient of thermal expansion and specific heat per unit volume. As distortion is determined by expansion and contraction of the material, the coefficient of thermal expansion of the material plays a significant role in determining the stresses generated during welding and, hence, the degree of distortion. For example, as stainless steel has a higher coefficient of expansion than plain carbon steel, it is more likely to suffer from distortion.

Amount of Restraint

If a component is welded without any external restraint, it distorts to relieve the welding stresses. So, methods of restraint, such as "strong-backs" in butt welds, can prevent movement and reduce distortion. Restraint results in higher levels of residual stress in the material leading to a greater risk of cracking in weld metal and heat affected zone (HAZ) especially in crack-sensitive materials.

Joint Design

Both butt and fillet joints are prone to distortion. It can be minimised in butt joints by adopting a joint type which balances the thermal stresses through the plate thickness. For example, a double-sided is preferred to a single-sided weld. Double-sided fillet welds should eliminate angular distortion of the upstanding member, especially if the two welds are deposited at the same time.

Part Fit-up

Fit-up should be uniform to produce predictable and consistent shrinkage. Excessive joint gap can also increase the degree of distortion by increasing the amount of weld metal needed to fill the joint. Relative movement between the parts during welding can be restricted by properly tacking the joint.

Welding Procedure

This influences the degree of distortion mainly through its effect on the heat input. As welding procedure is usually selected for reasons of quality and productivity, the welder has limited scope for reducing distortion. As a general rule, weld volume should be kept to a minimum. Also, the welding sequence and technique should aim to balance the thermally induced stresses around the neutral axis of the component.

12.4 CONTROLLING DISTORTION

You can control the distortion caused by expansion and contraction during welding by following the simple procedures listed here.

12.4.1 Control the Heat Input

It is advisable not to overheat in welding. Minimum heat input to provide a stable arc with good fusion and penetration should be used. To solve the problem of overheating welding should be done fast. The faster a weld is made, lesser is the heat absorbed by the base metal. Though by experiences welding process can be speeded up generating minimum amount of heat. It is often necessary to use a welding technique designed to control heat input. An intermittent weld (sometimes called a skip weld) in place of one continuous weld is one of the ways of controlling the heat input. When using an intermittent weld, a short weld is made at the beginning of the joint. Next, skip to the center of the seam and weld a few inches. Then, weld at the other end of the joint. Finally, return to the end of the first weld and repeat the cycle until the weld is finished. Figure 12.4 shows the intermittent weld.

Figure 12.4 : Intermittent Welding

Another technique to control the heat input is the back-step method (Figure 12.5). When using this technique, you deposit short weld beads from right to left along the seam. Then again go to a step further to the end of the second bead and weld from top to bottom. (Figure 12.5(a)). Continue this way till the job finishes. Even the back-step welding can be intermittent (Figure12.5(b)).

(a) Intermittent Welding **(b) Continuous Welding**

Figure 12.5 : Back-step Welding

Another way of controlling the heat input is by Limiting the Number of Weld Passes**.** Distortion can be kept to a minimum by using as few weld passes as possible. Number of weld passes should be limited to the number necessary to meet the requirements of the job (Figure 12.6).

Figure 12.6 : Weld Passes

12.4.2 Preheat the Metal

As discussed earlier, expansion and contraction rates are not uniform in a structure during welding due to the temperature differences throughout the metal. To control the forces of expansion and contraction, you preheat the entire structure before welding. After the welding is complete, you allow the structure to cool slowly. Preheating reduces the thermal stresses by reducing the temperature gradient in the weld zone.

12.4.3 Allow for Distortion

A simple remedy for the distortion caused by expansion and contraction is to allow for it during fit-up. To reduce distortion, you angle the parts to be welded slightly in the opposite direction in which the contraction takes place. When the metal cools, contraction forces pull the pieces back into position. Figure 12.7(a) shows how distortion can be overcome in both the butt and tee joints.

If it is not possible to prevent distortion at the design stage, distortion can be prevented by pre-setting and pre-bending of the part. It can also be prevented by the use of restrain. The technique will depend upon the type of component like its size and complexity, cost of equipment and the maximum allowable stresses. Details about the pre-setting, pre-bending and restraints are given below.

Pre-setting of Parts

The parts are pre-set and left free to move during welding (Figure 12.7). In practice, the parts are pre-set by a pre-determined amount so that distortion occurring during welding is used to achieve overall alignment and dimensional control.

The main advantages compared with the use of restraint are that there is no expensive equipment needed and there will be lower residual stress in the structure. Unfortunately, as it is difficult to predict the amount of pre-setting needed to accommodate shrinkage, a number of trial welds will be required. For example, when MMA or MIG welding butt joints, the joint gap will normally close ahead of welding; when submerged arc welding; the joint may open up during welding. When carrying out trial welds, it is also essential that the test structure is reasonably representative of the full size structure in order to generate the level of distortion likely to occur in practice. For these reasons, pre-setting is a technique more suitable for simple components or assemblies.

Figure 12.7 : Pre-setting of Parts to Produce Correct Alignment after Welding

(a) Pre-setting of fillet joint to prevent angular distortion

(b) Pre-setting of butt joint to prevent angular distortion.

(c) Tapered gap to prevent closure

Pre-bending of Parts

Pre-bending, or pre-springing the parts before welding is a technique used to pre-stress the assembly to counteract shrinkage during welding. As shown in Figure 12.8, pre-bending by means of strongbacks and wedges can be used to pre-set a seam before welding to compensate for angular distortion. Releasing the wedges after welding will allow the parts to move back into alignment.

Figure 12.8 : Pre-bending, using Strongbacks and Wedges, to Accommodate Angular Distortion in Thin Plates

12.4.4 Use of Restraint

Restraint is the more widely practised technique than pre-bending and pre-setting because of difficulties in applying them. The basic principle is that the parts are placed in position and held under restraint to minimise any movement during welding. When removing the component from the restraining equipment, a relatively small amount of movement will occur due to locked-in stresses. This can be cured by either applying a small amount of pre-set or stress relieving before removing the restraint. When welding assemblies, all the component parts should be held in the correct position until completion of welding and a suitably balanced fabrication sequence should be used to minimise distortion.

Welding with restraint will generate additional residual stresses in the weld which may cause cracking. When welding susceptible materials, a suitable welding sequence and the use of preheating will reduce this risk. Restraint is relatively simple to apply. Methods to apply restraints are given below :

Welding Jigs and Fixtures

Since holding the metal in a fixed position prevents excessive movements, the use of jigs and fixtures can help prevent distortion. A jig or fixture is simply a device used to hold the metal rigidly in position during the welding operation. Jigs are used to locate the parts and to ensure that dimensional accuracy is maintained whilst welding. They can be of a relatively simple construction, as shown in Figure 12.9(a), but the welding engineer will need to ensure that the finished fabrication can be removed easily after welding.

Figure 12.9(a) : An Example of Welding Jig and Fixture

Flexible Clamps

A flexible clamp Figure 12.9(b) can be effective not only in applying restraint but also in setting up and maintaining the joint gap (it can also be used to close a gap that is too wide).

Figure 12.9(b) : Flexible Clamps Used in Welding

A disadvantage is that as the restraining forces in the clamp will be transferred into the joint when the clamps are removed, the level of residual stress across the joint can be quite high.

Strongbacks (and Wedges)

Strongbacks are a popular means of applying restraint especially for site work. Wedged strongbacks (Figure 12.9(c)), will prevent angular distortion in plate and help to prevent peaking in welding cylindrical shells. As these types of strongback will allow transverse shrinkage, the risk of cracking will be greatly reduced compared with fully welded strongbacks.

Fully welded strongbacks (welded on both sides of the joint) will minimise both angular distortion and transverse shrinkage (Figure 12.9(d)). As significant stresses can be generated across the weld which will increase any tendency for cracking, care should be taken in the use of this type of strongback.

Figure 12.9(c) : Strongbacks with Wedges

Figure 12.9(d) : Fully Welded Strongbacks

Sometime inspite of taking all the precautions at the time of welding, it becomes impossible to eliminate the deformation caused due to residual stresses, so it is necessary to know how this can be corrected afterwards. In the next sections these corrective techniques have been discussed.

12.5 CORRECTIVE TECHNIQUES

Residual stresses may be eliminated by both thermal and mechanical means. During thermal stress relief, the weldment is heated to a temperature at which the yield point of the metal is low enough for plastic flow to occur and thus allow relaxation of stress. In the process, the mechanical properties of the weldment may also change, usually but not always toward a more uniform distribution across the joint. For example, the brittle fracture resistance of many steel weldments is improved by thermal stress relief not only because the residual stresses in the weld are reduced, but also because hard weld heat-affected zones are tempered (and therefore rendered tougher) by this procedure. Mechanical stress relief treatments will also reduce residual stresses, but will not change the microstructure or hardness of the weld or heat-affected zone. Peening, proofstressing, and other techniques are applied to weldments to accomplish these ends. Mechanical and thermal techniques are discussed briefly in the following section.

12.5.1 Mechanical Techniques

The principal mechanical techniques are hammering and pressing. Hammering may cause surface damage and work hardening. In cases of bowing or angular distortion, the complete component can often be straightened on a press without the disadvantages of hammering. Packing pieces are inserted between the component and the platens of the press. It is important to impose sufficient deformation to give over-correction so that the normal elastic spring-back will allow the component to assume its correct shape.

In long components, distortion is removed progressively in a series of incremental pressings; each one acting over a short length. In the case of the flanged plate, the load should act on the flange to prevent local damage to the web at the load points. As incremental point loading will only produce an approximately straight component, it is better to use a former to achieve a straight component or to produce a smooth curvature.

12.5.2 Thermal Techniques

The basic principle behind thermal techniques is to create sufficiently high local stresses so that, on cooling, the component is pulled back into shape.

This is achieved by locally heating the material to a temperature where plastic deformation will occur as the hot, low yield strength material tries to expand against the surrounding cold, higher yield strength metal. On cooling to room temperature the heated area will attempt to shrink to a smaller size than before heating.

Figure 12.10(a) : Local Heating

The stresses generated thereby will pull the component into the required shape. Local heating is, therefore, a relatively simple but effective means of correcting welding distortion. Shrinkage level is determined by size, number, location and temperature of the heated zones. Thickness and plate size determines the area of the heated zone. Number and placement of heating zones are largely a question of experience. For new jobs, tests will often be needed to quantify the level of shrinkage. There are a number of technique to apply thermal correction after distortion like spot, line, or wedge-shaped heating s*pot heating.*

Spot heating is used to remove buckling, for example when a relatively thin sheet has been welded to a stiff frame. Distortion is corrected by spot heating on the convex side. If the buckling is regular, the spots can be arranged symmetrically, starting at the centre of the buckle and working outwards.

Figure 12.10(b) : Spot Heating

Figure 12.10(c) : In-Line Heating

Line Heating

Heating in straight lines is often used to correct angular distortion, for example, in fillet welds. The component is heated along the line of the welded joint but on the opposite side to the weld so the induced stresses will pull the flange flat.

Wedge-shaped Heating

To correct distortion in larger complex fabrications it may be necessary to heat whole areas in addition to employing line heating. The pattern aims at shrinking one part of the fabrication to pull the material back into shape.

Apart from spot heating of thin panels, a wedge-shaped heating zone should be used, from base to apex and the temperature profile should be uniform through the plate thickness. For thicker section material, it may be necessary to use two torches, one on each side of the plate. As a general guideline, to straighten a curved plate wedge dimensions should be :

- Length of wedge – two-thirds of the plate width
- Width of wedge (base) – one sixth of its length (base to apex)
- The degree of straightening will typically be 5mm in a 3m length of plate.

Wedge-shaped heating can be used to correct distortion in a variety of situations :

- Standard rolled section which needs correction in two planes
- Buckle at edge of plate as an alternative to rolling
- Box section fabrication which is distorted out of plane

Figure 12.10(d) : Wedge Heating

General Precautions

The dangers of using thermal straightening techniques are the risk of over-shrinking too large an area or causing metallurgical changes by heating to too high a temperature. As a general rule, when correcting distortion in steels the temperature of the area should be restricted to approximately to 60° - 650°C dull red heat. If the heating is interrupted, or the heat lost, the operator must allow the metal to cool and then begin again.

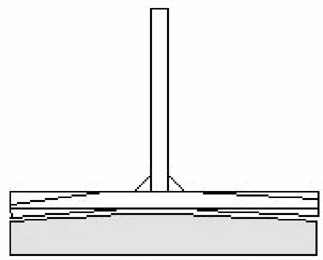
Till now in this unit we have studied distortion caused due to residual stresses. But this is not the only defect which we have to take care of while welding. There are number of other defects which are to be taken care of while welding. These can occur due to various factors involved during welding. In the next section we are going to discuss the other welding defects which can commonly occur.

Example 12.1

How can you prevent the distortion shown in figure below, which is the result of welding equally on both sides. In this case the upright remains vertical but the base piece is bowed.

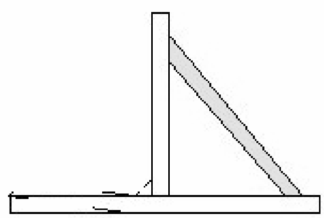
Solution

The best solution to prevent the distortion shown above is to prebend the assembly against the brace or strong back as shown below.



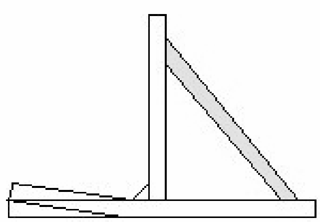
Example 12.2

In the case explained below with the help of diagram, what kind of distortion is expected and why?



Solution

In this case welding is of T-joint on one side. The brace will ensure that the relationship between the right side and the upright will stay close to ninety degrees however the left side is free to shrink and distort as shown in figure below.



SAQ 1

(a) What is distortion? Explain four ways to control distortion in base metal.

(b) What causes distortion?

(c) To avoid distortion after welding parts are held in specially designed fixtures. Won't holding parts in a restrained condition like this create a lot of stress?

(d) How does distortion occur when welding? What is the sequence of events?

(e) What effect does the physical and mechanical properties of the material have on the degree of distortion?

(f) How does the coefficient of thermal expansion, thermal conductivity and yield strength of a material effect distortion?

12.6 OTHER WELDING DEFECTS

Other than distortion there are number of welding defects which can lead to the failure of the weld when put to service conditions. Defects in fusion welded joints may be generally classified into three major groups : namely process and procedures related, metallurgical and design related. The process procedure and design related defects are most commonly found. Some metallurgical defects may vary the local stress distribution but those connected with the microstructure may also change the properties of the metal and provide metallurgical notch effects.

Defects be seen only on the basis of their nature but their shape also matters that is whether they are essentially planar or are three-dimensional. Planar types such as cracks, laminations, incomplete fusion and inadequate joint penetration generally have more pronounced stress amplification effects than three dimensional defects.

- Size
- Sharpness
- Orientation with respect to the principal working stress and residual stresses, and
- Location with respect to the weld and to the exterior surfaces of the joint should be considered.

Defects oriented or positioned where stresses tend to enlarge them are more detrimental than those that are not so positioned. Also surface or near surface defects be more detrimental than similarly shaped internal discontinuities. There are a number of types of weld defect categories as shown in the figure below.

Figure 12.11 : Weld Defects

Below is a brief description of some of the major defects.

12.6.1 Porosity

Porosity occurs as a result of gas entrapment in the molten metal during a weld or through improper cleaning of the joint during preparation of the weld. Porosity depending on several conditions can have negative effects on weld performance. The degree of porosity in a weld is determined by the amount, size and the distribution (uniform, clustered, linear, elongated) of the pores (Figure 12.11).

Due to porosity dimension of the weld cross-section is lowered and thus its strength. If porosity is located close to or at the surface, fatigue strength may be effected. Depending to some extent on the shape of the voids and the chemistry of their walls they may initiate crackin g. If located near the toe of fillets or at the edge of weld reinforcements which are stress concentration areas they may initiate cracking. Cleaning is important to avoid porosity but welding techniques may also be involved in which the weld is allowed to solidify before gas can escape. One of the ways of doing this is that weld speed may have to be reduced or techniques involving oscillation may be needed. This will reduce the chances of gas entrapment which results in porosity. Preheating is another way of reducing the cooling rate allows some gases to diffuse away and therefore reducing the porosity.

Keyhole welding utilizing either electron beam or laser are prone to porosity entrapment due to their very narrow welds though vapour pressure probably expels some porosity. Chill fixtures may accelerate weld solidification and trap gas bubbles.

Most welds probably have some porosity and may be acceptable provided it is within the weld or product specification limits.

To prevent porosity fillers with adequate level of dissidents may be used. It is also possible to reduce porosity by use of dried electrode and flux. Cleaning of workpiece surface, joint edges is another solution. Even the coatings from the joint area should be removed.

12.6.2 Cracks

Cracks may occur in either the weld or base metals being joined. Cracks are the major threats to the survival of the weldment and hence rarely acceptable. Due to the cracks stress concentration areas are formed at their extremities which help these cracks to propagate further. There is a wide variety of crack types transverse, longitudinal and so on, each with sub-definitions. There are a number of crack types that are common in the weld and a number that are more common in the base metal.

Figure 12.12 : Example of Crack

Cracks can occur on solidification of the weld pool. Number of factors influence such cracks like insufficient weld pool size, restrained welding and impurities present in the material. Cracks can also be the result of high porosity which can propagate a crack.

The joint design can increase the risk of cracking. For example, joints likely to contain stress concentration, such as partial penetration welds, are more liable to initiate cracks. The welding procedure also has an influence. Large weld beads are undesirable as they produce a coarse grained heat affected zone (HAZ) which is less likely to be refined by the subsequent pass and therefore will be more susceptible to reheat cracking. The total thickness of the material at the joint line will also determine the cooling rate of HAZ and its hardness. If the base material thickness is same fillet welds will have greater risk of having crack than a butt weld. In short the following techniques should be applied to avoid cracking

- dry the electrodes or the flux in accordance with the manufacturer's recommendations,
- reduce stresses on the weld by avoiding large root gaps and high restraint,
- if preheating is specified in the welding procedure, it should also be applied when tacking or using temporary attachments,
- preheat the joint to a distance from the joint line to ensure uniform heating through the thickness of the material,
- adhere to the heat input requirements,

- post heat for approximately two to four hours after welding depending on crack sensitivity,
- In situations where adequate preheating is impracticable, or cracking cannot be avoided, austenitic electrodes may be used, and
- clean the joint faces and remove contaminants such as paint, cutting oils, grease.

All these defects can be reliably recognised using ultrasonic inspection techniques with the exception of gas pores. Gas pores are harder to accurately monitor due to the small size of the flaw. If a crack is detected after welding, it should be removed by rewelding if possible, using the correct specified procedure.

12.6.3 Slag Inclusions/Entrapment

These types of defects are characteristic to multiple pass welds and those processes that use a slag covering for shielding purposes. They are usually found at the side or surface of a join (Refer Figure 12.11). Slag is the by-product of a weld. It is brittle and can therefore lead to a reduction in the quality of joint strength when it is trapped below the surface.

As slag is the residue of the flux coating, it is principally a deoxidation product from the reaction between the flux, air and surface oxide. The slag becomes trapped in the weld when two adjacent weld beads are deposited with inadequate overlap and a void is formed. When the next layer is deposited, the entrapped slag is not melted out. Slag may also become entrapped in cavities in multi-pass welds through excessive undercut in the weld toe or the uneven surface profile of the preceding weld runs.

As they both have an effect on the ease of slag removal, the risk of slag imperfections is influenced by

- Type of flux
- Welder technique

The type and configuration of the joint, welding position and access restrictions all have an influence on the risk of slag imperfections.

Welding technique has an important role to play in preventing slag inclusions. Correct size of electrode for the joint preparation, the correct angle of the workpiece for good penetration and a smooth weld bead profile all are essential to prevent slag entrainment.

In multi-pass vertical welding, especially with basic electrodes, care must be taken to fuse out any remaining minor slag pockets and minimise undercut. When using a weave, a slight dwell at the extreme edges of the weave will assist sidewall fusion and produce a flatter weld bead profile.

Too high a current together with a high welding speed will also cause sidewall undercutting which makes slag removal difficult. When going for more than one pass, it is crucial to remove all slag before depositing the next run. This can be done between runs by grinding, light chipping or wire brushing. Cleaning tools must be identified for different materials e.g. steels or stainless steels, and segregated.

When welding with difficult electrodes, in narrow V-butt joints or when the slag is trapped through undercutting, grinding between the layers can ensure complete slag removal.

12.6.4 Incomplete Fusion and Penetration

Fusion refers to the degree to which base metal surfaces are fused to their metal filler, while penetration refers to the degree to which metal surfaces have been melted together to form the throat of a weld. Both of these defects can be the result of a poor welding technique by the technician involved or due to poor weld preparation that could leave elements on the specimen that impair the full melting of surface metals. The need for effective pre-weld cleaning and shielding of the weld joint and weld pool during welding is evident.

These types of imperfection are more likely in consumable electrode processes (MIG, MMA and submerged arc welding) where the weld metal is 'automatically' deposited as the arc consumes the electrode wire or rod. The welder has limited control of weld pool penetration independent of depositing weld metal. Thus, the non-consumable electrode TIG process in which the welder controls the amount of filler material independent of penetration is less prone to this type of defect. Incomplete root fusion can be reduced by using the correct welding parameters and electrode size to give adequate arc energy input and deep penetration. Electrode size is also important in that it should be small enough to give adequate access to the root, especially when using a small bevel angle (as shown in figure). It is common practice to use smaller diameter electrode for the root so the welder can manipulate the electrode for penetration and control of the weld pool. However, for the fill passes where penetration requirements are less critical, a larger diameter electrode is preferred to achieve higher deposition rates.

(a) Incomplete Fusion **(b) Incomplete Penetration**

Figure 12.13 : Lack of Fusion and Penetration

Current level has to be optimized. Too low a current level for the size of root face will give inadequate weld penetration. Too high a level, causing the welder to move too quickly, will result in the weld pool bridging the root without achieving adequate penetration. It is also essential to set the joint gap accurately. To prevent the gap from closing, adequate tacking will be required.

Inadequate penetration can be the basis for weld joint failure due to its stress concentration effect and reduced material section. Weld joints for which less than 100% penetration is specified should if possible include radius at the edges or other criteria at the root of the weld joint to distribute rather than conc entrate stresses.

12.6.5 Undercutting

Undercutting along the edge of the weld is usually the result of poor welding technique or the use of unsuitable parameters. The undercut may have a notch effect and a stress riser and promote cracking. In addition undercutting may significantly lower the joint cross section and therefore lower its strength.

Figure 12.14 : Defective Weld Due to Undercut

12.6.6 Suck Back and Drop Through

Suck back and drop through can be considered to be related defects. Suck back is caused by the shrinkage of the deposited filler metal because it has not been adequately bonded or fused to the faying surfaces of the weld joint. Therefore as the melt shrinks and by surface tension it is pulled up from the root. This implies improper or inadequate heating and or cleaning. Residual oxides or other inhibiting contaminants on the weld joint surfaces can prevent wetting and bonding.

Figure 12.15 : Suck Back and Drop Through During Welding

Drop through can occur if the weight of the weld melt exceeds the ability of the surface tension to hold the melt in suspension within the weld joint while it fuses and solidifies. For example, a deep penetration weld involving a considerable volume and weight of molten weld metal. This condition is also influenced by an excess width of the weld joint gap, thickness of the details, the time at melting temperature and weld joint surface cleanliness. Lack of wetting fusion resulting from inadequate cleaning can contribute to "drop through."

Example 12.3

Two solid bars of exactly same size as shown in figure are subjected to same cyclic loading. Which one will fail first?

Solution

Where the toes of weld join the parent material small intrusions exist at the interface usually at the base of w eld undercut. Dressing the weld toes by grinding will improve fatigue life, shot peening the weld (putting the outer fibres in compression) will give further improvements, but the intrusions will still exist and will eventually propagate a fatigue crack under the right conditions.

Therefore when considering the fatigue of a welded joint the assumption is made that a crack has already been initiated and the fatigue mechanism is simply the propagation of that crack. This makes fatigue calculations much easier as there are fewer variables to consider, for example the fatigue graph of a steel weld can be used to predict the fatigue performance of a weld in aluminium providing allowance are made for the difference in Young's modulus.

Only cycling tensile stresses will cause crack propagation, however in a welded joint, even after post-weld heat treatment there could be significant amounts of residual strew which could be as high as the yield stress. Under certain conditions the residual stress could convert a varying compressive stress in to a varying tensile stress, therefore it is prudent to consider all stress variations, both tensile and compressive when considering the fatigue of a welded joint.

Therefore bar containing the fillet weld will fail first. The difference in performance will generally become greater as life cycles increase.

SAQ 2

(a) What should be taken care of while designing a welded joint?

(b) What is the difference between incomplete fusion and penetration?

(c) How does suck back and Drop through differ? What is the effect of these on the weld strength?

(d) What is the purpose of Preheat?

(e) What considerations should be kept in mind while welding to reduce weld defects?

12.7 SUMMARY

Now-a-days welding is the most common method used for joining, largely because of the speed at which joints can be made and the reliability of these joints in service. However, because most welding operations are now relatively simple to perform it is all too easy to forget the complexity of the chemical and metallurgical actions that are taking place when the weld is being deposited. Therefore, not surprisingly, welds often develop weld defects.

In this unit, characteristic features and principal causes of common weld defects are described. Residual stresses and the distortion which takes place due to these is discussed. Various ways to control the distortion while welding are also included. Once the component is distorted due to residual stresses, remedies to correct them have also been given. During welding it is not only the distortion which is to be taken care of, rather other welding defects are also to be kept in mind. These are briefly given in this unit. General guidelines to prevent them are discussed, so that welders can minimise the risk of imperfections during fabrication. Emphasis is placed on weld distortion, its causes and remedies.

12.8 KEY WORDS

Crack : A linear discontinuity produced by fracture. Cracks may be longitudinal, transverse, edge, crater, centre line, fusion zone, underbead, weld metal or parent metal.

Porosity : A group of gas pores.

Spatter : Globules of metal expelled during welding on to the surface of parent metal or of a weld.

Step-Back Sequence : A welding sequence in which short lengths of run are deposited in a direction opposite to the general progress of welding the joint. The short lengths eventually produce a continuous or intermittent weld.

Tack Weld : A weld used to assist assembly or to maintain alignment of edges during welding.

Undercut : An irregular groove at a toe of a run in the parent metal, or in previously deposited weld metal, due to welding.

12.9 ANSWERS TO SAQs

SAQ 2

(d) Purpose of preheat :-

- Reduce the risk of hydrogen cracking
- Reduce the hardness of the weld heat affected zone
- Reduce shrinkage stresses during cooling and improve the distribution of residual stresses.

(e) Considerations which are to be kept in mind are

- Design of the weld based on the loading condition(s) the joint will carry
- Accessibility to enable ease of welding
- Control of distortion

- Careful consideration of the welding environment
- Matching welding process with materials
- A factor of safety applied to the design stress of the weld which should be based on the consequence of weld failure and the level of non destructive testing that is to be carried out.