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Welding Joint Defects in Steel Fabrication: Identification, Causes and Quality Control in Small-Scale Metal Workshops

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Abstract
Welding is the most popular permanent joining process used in structural, architectural, and general metal fabrication. Still, the quality of the weld is only as good as the joint from which it is built. This article looks at some of the common welding joint defects found in small-scale steel fabrication workshops, using pictures from a real steel fabrication job using mild steel angle bars and mild steel tubing. The paper summarizes the various types of welding joints: mitre (corner), butt, T-joints, and lap joints, and covers some common welding joint defects: poor fit-up and root gaps, porosity, incomplete fusion, undercut, spatter, and distortion. The causes of the problems are identified as joint preparation, welding parameters, electrode selection, operator skill, and environmental conditions, and references are made to the welding metallurgy and fabrication literature. The photographs show correct and incorrect practice at each of these stages, from marking to bevelling, arc welding to the finished product. Finally, the authors conclude that most of the defects that occur in an artisanal welding environment can be avoided by proper joint preparation, correct selection of welding parameters, and simple quality evaluation and control practices, and suggest practical suggestions for reducing the occurrence of defects in resource-challenged welding environments like those found in Ghana and the rest of the West African sub-region.

Keywords: welding joint defects, joint fit-up, weld porosity, fabrication quality control

1. Introduction

Welding is a process of fabrication that is used to join materials, typically metals, through the application of heat, pressure or pressure and heat (Messler, 2004) [7]. The arc welding processes are still the most popular methods in structural steelwork, the fabrication of gates, window guards and general artisanal metalwork, due to their low cost, portability and use in site and workshop conditions where most of the small and medium scale fabrication enterprises operate in Ghana (Kah *et al*., 2013) [5]. Skill of the welder during arc initiation and bead deposition, however, is not the only factor to influence the strength, durability and appearance of a welded structure; most importantly, quality of the joint that is prepared prior to the arc being struck (Cary & Helzer, 2005) [3]. In fact, even the best welding skills can fail because of poor fit-up, incorrect bevel angles, or contaminated surfaces, which can cause defects that can affect the functional or form appearance. In fast-paced production this preparatory phase can be overlooked and can make or break the entire welding operation. A weld joint defect is an irregularity or discontinuity that is identified in the weld metal or HAZ that is not within acceptable limits based on a fabrication standard or code, for example, AWS D1.1 Structural Welding Code, Steel (American Welding Society [AWS], 2015) [1]. Mechanical integrity is affected by defects by reducing the fatigue life of a joint, by creating stress concentrations, and in the case of visible fabrication work (such as balustrades, burglar-proofing and decorative ironwork), by degrading the surface finish and market value (ASM International, 1993) [2]. Some common defects are porosity (rounded cavities due to trapped gases), slag inclusions (linear or angular entrapped non-metallic solids), lack of fusion (where weld metal fails to fuse with the base metal) and undercut (where weld metal melts a groove into the base metal next to the weld toe). Every defect will have a unique visual appearance (porosity will appear as a spongy or pocked surface and undercut will appear as a sharp notch along the edge of the weld) and will require specific countermeasures, including correct cleaning, electrode positioning, and heat input.

In the informal and semi-formal fabrication setting, where quality assurance is often the only quality assurance, it is important to understand the different types of defects, what causes them, and how they appear (Jenney & O'Brien, 2001) [4]. These workshops depend largely upon the welder's eye and experience to find flaws when no other non-destructive testing equipment is available such as radiography or ultrasonic testing. The arc sound, weld pool shape and the movement of the slag can be used by a trained operator to detect incipient problems during welding. Also, knowing that defects can occur from a combination of factors, for example, if the electrodes are damp, there will be porosity; if the travel velocity is too high, there will be underfill, which can all be corrected proactively instead of being repaired reactively. In conclusion, raising defect awareness among the fabricators of the Ghanaian market helps to improve structural safety, boost the professionalism and competitiveness of the local metalwork industry, minimize rework costs for the fabricators and consequently ensure client satisfaction both locally and internationally.

2. Types of Welding Joints in Steel Fabrication

The purpose of this article is to show the main types of welding joint defects, their causes and preventative practice by using a photographic record of an actual fabrication job using angle iron (mild steel), square tube, round tube and branch (saddle) pipe joint plus a set of finished galvanised security panels. The discussion is structured around joint type, categories of defects, and causes of defects, and ends with recommendations applicable at the workshop level of QA. There are several types of welding joints, which are described below in steel fabrication. In welding practice, five basic joint configurations are known: butt, corner, T, lap and edge joints, which each have a specific edge preparation geometry to ensure complete fusion (AWS, 2015; Kou, 2003) [1, 6]. The methods described in this article are mainly concerned with the corner joint (mitre) and the T-joint (branch connection) – both of which are common applications in the production of gates, window guards and handrails.

2.1. The Mitre (Corner) Joint

A mitre joint is one that is created by two pieces of angle iron, flat bar or tubing that are cut at complementary angles (usually 45°) to snap into a right-angle corner without an overlapping member. The mitre joint is extremely dependent on marking-out and cutting precision due to being edge-to-edge with no natural overlap to compensate for inaccurate cutting (Cary & Helzer, 2005) [3]. The marking and grinding operation for making a mitre joint in angle iron is illustrated in Fig. 1, where the angle to be cut is marked on the iron with lines and the cut is made by the abrasive cut-off wheel which produces the bevel angle that is required.

Fig 1: Marking-out and abrasive grinding of a 45° mitre bevel on mild steel angle iron.

After cutting, the two mitred faces are joined to inspect fit-up before welding is done. Figure 2 shows the checking stage, with the corner of an angle-iron frame having two mitred faces with a visible root gap evident along part of the joint line, which is discussed further in Section 3.1.

Fig 2: Mitre corner joint of angle iron prior to welding.

2.2. Tubular Corner and Branch Joints

Again, round and square hollow-section tube is connected with the same principle of corner-mitres, but since it is hollow, an improperly aligned cut creates an opening into the interior of the tube instead of just a gap. This is illustrated on round tube in Figure 5 (Section 5). Where a smaller tube is joined perpendicular to a larger tube, this is called a branch or saddle connection, and requires a profiled 'fish-mouth' or coped cut to ensure that the branch member is fully seated against the curve of the main member; see Figure 6 for a T-branch connection of this type.

3. Most Common Welding Joint Defects

Welding defect is traditionally distinguished according to its position: surface or internal defects and according to its metallurgical or geometric aspect: asm-international 1993. The fabricator sequence used in this document has the most pertinent defects discussed below.

3.1. Poor Fit-Up and Root Gaps

Fit-up is the term used for the precision with which two members are fitted together and mated prior to welding. Unawareness in marking, cutting or handling distortion causes excessive or uneven root gaps, which cause the welder to have to add extra filler metal to fill the gap, resulting in the risk of burn-through, porosity and residual stress (Kou, 2003) [6]. Figure 2 and 5 illustrate that the root gap between the two plates is open at the mitre joint before welding and in thin wall tube, the shielding gas and arc energy can escape through to the bore, affecting the quality of the fusion (Mohandas, Madhusudhan Reddy, & Naveed, 1999) [8].

Fig 3: Mitred corner joint of round steel tubing showing an open root gap and a partly cut, unclosed section of the tube wall.

3.2. Porosity (Blow Holes)

Porosity is the inclusion of gas in the weld solidifying pool, which forms rounded pockets that are either seen on the surface of the welds or when the weld is cut open, at the center of the weld metal (ASM International, 1993) [2]. Common causes include moisture on the joint faces, contaminated and damp electrodes, excessive arc length, inadequate shielding at the arc, which all allow the nitrogen, hydrogen, and oxygen of the atmosphere to become trapped in the weld pool during cooling (Kou, 2003) [6]. When viewing a corner weld along the length of the weld, multiple surface-breaking voids, along with an incomplete closure of the root, are seen in Figure 4, a characteristic of both porosity and marginal fusion.

Fig 4: Close-up of a finished mitre corner weld on angle iron showing surface porosity (rounded voids along the weld bead) and an incompletely fused root gap.

3.3. Incomplete Fusion

Lack of fusion will occur when the weld metal does not meld completely with the base material or with the previous pass of weld metal and a plane of non-bonded material will form that acts as a stress concentrator and crack initiation point (Messler, 2004) [7]. It usually occurs when there is an inadequate heat input, poor electrode angle, too fast of a travel speed or an unclosed root gap that the arc cannot effectively bridge in a single pass (AWS, 2015) [1] as shown in Figure 4. Since lack of fusion is often invisible from the outside, it is one of the most dangerous defects in load-bearing structural welds, and cannot always be detected visually (ASM International, 1993) [2].

3.4. Undercut and Heat-Affected Surface Damage

Undercut is a groove melted into the base metal at the toe of the weld, which is not filled, and thus lowers the effective cross-section of the base metal (Cary & Helzer, 2005) [3]. Usually caused by using too much welding current, the wrong angle of the electrode or by using too high an arc travel rate. Figure 6 illustrates a branch pipe fillet weld with localised heat discolouration (temper colours) around the joint edge, with spatter deposits along with evidence of a high heat input and poor arc control at the joint edge, which all contribute to the undercutting of the joint and reduced fatigue performance.

Fig 5: Fillet weld at a T-branch pipe connection.

3.5. Weld Spatter

Spatter is the molten metal particles that are ejected from the weld pool during arc welding and fall on the base metal, causing surface damage and if left on the surface, acting as stress risers or corrosion initiation points (Kah *et al*., 2013) [5]. The factors that affect spatter are welding current, arc length, condition of the electrode coating, and electrode polarity. Spatter generation is a normal by-product of the arc welding process and is shown in Figure 7 as spatter droplets on the surrounding plate while an active shielded metal arc weld was performed at a corner joint.

Fig 6: Shielded metal arc welding in progress at a mitre corner joint of mild steel plate.

3.6. Distortion, Segment Misalignment and Cumulative Bend Defects

Avoiding Defects: 3.6 Distortion, Segment Misalignment and Cumulative Bend Defects Defects can occur when a curved member is fabricated by a series of relief (kerf) cuts made in a straight square tube and then closed with a weld; as is done for handrails and balustrade returns; due to non-uniform spacing of the cuts; due to non-uniform closure of each cut; or due to incomplete penetration at the base of each kerf weld (Messler, 2004) [7]. The segmented bending process is demonstrated in Figure 8 at two points; with kerf cuts open and with the corresponding welds in place and bent to close the bend. Even consistent spacing of segments and full-depth fusion of the base of each segment are fundamental to avoid having a lumpy, uneven curve or weak points in the bend.

Fig 7: Close-up of a segmented (kerf-cut) bend in square tube. Wedge-shaped relief cuts have been made at regular intervals to allow the tube to be curved.

Fig 8: Wider view of the same segmented bend, showing the transition from the curved handrail section into the straight vertical post.

4. Underlying Causes of Welding Joint Defects

In this lesson, students will learn about the causes of defects in welds.In this lesson, students will learn what causes weld defects. Four large causal groups have been consistently mentioned in the literature and confirmed by the fabrication sequence provided above, across the various defect categories discussed. Joint preparation: Uneven root gaps are created by inaccurate marking-out, cutting or bevel-grinding (Figures 2 and 5), and cause the need for excessive filler deposition and risks of porosity and incomplete fusion (Kou, 2003) [6]. Welding parameters such as incorrect current, arc length, and travel speed result in spatter, undercut, and heat-tinting (Figures 4, 5 and 6), and are cited as the most common causes of weld discontinuities in structural fabrication (AWS, 2015) [1]. Hydrogen- and nitrogen-induced porosity are the main causes of consumable and surface conditions, such as damp or poorly stored electrodes, and rust, oil, mill scale, or moisture on the joint faces (ASM International, 1993) [2]. Defect free joints are created when the operator has skill and practice in the use of her/her arc welder, and when she or he performs fit-up checks systemically, and not just by the welder's eye (Cary & Helzer, 2005; Jenney & O'Brien, 2001) [3, 4].

5. From Defect Prevention to Finished Product

Finally, the human and economic issues in a resource-limited environment need to be addressed when talking about defect prevention. The total cost of the jigs, angle guides, covered electrode storage and visual checklists is relatively low in comparison to the total rework, material waste and lost confidence in the product being built due to uncontrolled defects. Even the smallest production defect or the production of unacceptable goods can result in a loss of weeks' worth of profit and can jeopardize a hard-earned reputation in a small-scale workshop where profit margins are razor-thin. On the other hand, the same limited investments carried out consistently reap compounded benefits over time: fewer batches of products are rejected, grinding and repair work done are lowered, use of consumables is decreased, and production cycles are accelerated because products are not delayed when a correction needs to be performed.

But there is a more intangible, yet significant advantage to the immediate financial equation: development of professional pride and workmanship identity. A mindset of quality within the workshop can be achieved by treating defects as a part of the job of the person in the shop, not an external obligation or an optional add-on; and it will lead to higher employee satisfaction and a long-term viable business. With the knowledge of why it is that defects occur and how they can be prevented, artisans become active problem-solvers, rather than mere operators, and assume control of their production. This change of attitude transcends the role of quality control into a common professional value which enables the learning from peers and the common accountability. Where formal certification schemes are not available, these internalised quality cultures are the best guarantee of consistent workmanship, allowing workshops to obtain higher prices, repeat orders and to be competitive in the domestic and export markets. In the end, the success of making businesses depends on the attitude and skills of the people in these businesses, not just on the amount of money and equipment.

Fig 9: Completed, galvanised steel window-guard and security panels, fabricated from welded angle-iron and bar-stock frames, awaiting installation.

6. Discussion

This photographic sequence illustrates the fact that the majority of the defects that are encountered on the weld root gaps, porosity, marginal fusion, spatter and heat tint caused by undercut risk are a result of the previous steps of marking, cutting and fit up. This is in line with the extensive welding engineering literature that has often cited joint preparation as the most critical factor in manual arc welding (Kou 2003; Messler 2004) [6, 7]. The evidence from Figures 2, 3 and 5 is particularly important in this regard, as it demonstrates that, even with the most advanced welding skills, open root gaps and misaligned edges are inherent weaknesses. Visual flaws like those shown in Figure 2, 4, 5 and 6 are the most readily obtainable and inexpensive criteria for assessing the quality of a workshop by a supervisor or client in small-scale and informal fabrication settings, common to the majority of the Ghanaian metalworking industry, where dedicated quality assurance staff and non-destructive testing equipment are not readily available (Jenney & O'Brien, 2001) [4]. It is interesting to note that the same causes are present in each of the very different joint geometries (flat mitre joints in angle iron, tubular corner joints, and branch pipe connections) and that a relatively small number of workshop practices would be effective in minimizing the majority of the defects observed, regardless of the joint geometry being fabricated (AWS, 2015; Cary & Helzer, 2005) [1, 3]. The photos in Figures 4 and 6 show that the problems of porosity and undercut are not necessarily geometry related, but rather are symptoms of other problems, such as wet electrodes, too high a current, or the wrong electrode angle. From a quality improvement point of view, this repetition of the causes of the defect across the joint types is encouraging, because if consumable storage, parameter verification, pre-weld inspection, are targeted as targets for improvement, they have the potential to achieve larger improvements in the overall quality of fabrication.

In addition, cumulative geometric error, a defect that is not widely discussed in the welding literature, becomes a factor of the cause of defect during the segmented bending process shown in Figures 7 and 8. Errors in a single-joint bend will only be a problem in a limited area, whereas in a segmented bend the errors from uneven kerf spacing or incomplete root fusion are a compound error, causing an irregular radius along the entire curved member. This is especially true for fabricators of handrails, balustrades and decorative ironwork, where the importance of uniformity is as great as the importance of structural strength. The panels in Figure 9 are complete and galvanised; the following text demonstrates the power of the systematic control of these various defect categories. The uniform bead appearance, lack of visible porosity, and uniform corner geometry across each panel proves that there is no need for expensive technology or exotic materials to achieve defect-free fabrication; it requires only that the basic elements accurate marking-out, careful fit-up inspection, dry consumables, and proper welding parameters are followed rigorously. Last but not least, the human and economic aspects in a resource constrained environment should not be ignored when discussing defect prevention. The investment required to implement the suggestions that is jigs, angle guides, covered electrode storage, visual checklists is relatively small compared to the cost of rework, material waste and client confidence lost due to uncontrolled defects. Viewing defect prevention as a part of the fabricator's job will help create a culture of quality within the workshop that will boost worker pride and sustain the business.

7. Conclusion and Recommendations

Joint defects are primarily preventable, in the vast majority of cases, when it comes to welding steel fabrication. The poor fit-up, porosity, lack of fusion, undercut, and excess spatter observed in this article was not due to sources outside the fabricator's control, but common causes found in joint preparation, consumable condition, and welding parameter control. Where these causes are systematically addressed the finished product as shown in the completed galvanised panels in Figure 9 is structurally sound and visually finished to meet the requirements of long-term fabrication that is marketable. Before welding, minimise the variation of root gaps by standardising marking out and cutting practices, such as using jigs or angle guides for cutting mitres (Figures 1, 2) Implement fit-up check, which is to close all the joints by hand and check for gaps, immediately before welding, and not just at the cutting stage. To minimize the risk of porosity, store electrodes in dry, covered condition, and before using these electrodes for welding, clean electro holes of rust, oil, mill-scale, and moisture (ASM International, 1993) [2] To control spatter and undercut, set and monitor the welding current, arc length and travel speed per the electrode manufacturer's recommendations and not by habit. In a segmented bend, relief cuts are made at even intervals that have been measured, and each bend is completely closed and fused at the base with the previous bend before moving on to the next bend, to obtain a smooth radius at the end. Implement basic visual inspection checklists that include fit-up, surface porosity, spatter and uniformity of beads at the workshop level as a viable non-destructive testing measure in a resource-limited fabrication environment. Encourage skills training or refresher training for the artisans who weld periodically to develop a common terminology based on evidence of the relationship between the arc parameters and the defects being formed, so that they can use this vocabulary to diagnose and correct defects in the field.

References

1. American Welding Society. Structural welding code—steel: AWS D1.1/D1.1M. Miami (FL): American Welding Society; 2015.
2. ASM International. Welding, brazing, and soldering. In: ASM handbook. Vol. 6. Materials Park (OH): ASM International; 1993.
3. Cary HB, Helzer SC. Modern welding technology. 6th ed. Upper Saddle River (NJ): Pearson Prentice Hall; 2005.
4. Jenney CL, O'Brien A, editors. Welding handbook. 9th ed. Vol. 1, Welding science and technology. Miami (FL): American Welding Society; 2001.
5. Kah P, Suoranta R, Martikainen J. Advanced gas metal arc welding processes. Int J Adv Manuf Technol. 2013;67(1-4):655-674.
6. Kou S. Welding metallurgy. 2nd ed. Hoboken (NJ): John Wiley & Sons; 2003.
7. Messler RW. Principles of welding: processes, physics, chemistry, and metallurgy. Weinheim: Wiley-VCH; 2004.
8. Mohandas T, Madhusudhan Reddy G, Naveed M. A comparative evaluation of gas tungsten and shielded metal arc welds of a 'ferritic' stainless steel. J Mater Process Technol. 1999;94(2-3):133-140.

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