Incomplete fusion in the root of a complete-joint-penetration (CJP) groove weld is a defect, but incomplete fusion in the root of a properly made PJP groove weld is an acceptable discontinuity.

Incomplete Joint Penetration

Incomplete joint penetration is "a joint root condition in a groove weld in which weld metal does not extend through the joint thickness" (AWS, 2010d). Incomplete joint penetration, also called lack of penetration, has various causes. For a CJP groove weld like that shown in Figure 9-2, incomplete joint penetration may be the result of improper backgouging of the double-sided joint detail. For joints where a prescribed amount of penetration is specified, incomplete joint penetration may be the result of incorrect electrode placement, an improper welding procedure (typically with low current levels), or an improperly prepared joint.

Overlap

Overlap is "the protrusion of weld metal beyond the weld toe or weld root" (AWS, 2010d). While the overlap itself is volumetric, the discontinuity it creates is planar. Overlap is an example of an incomplete fusion discontinuity that occurs on the surface of the steel as shown in Figure 9-3.

Overlap tendencies may be aggravated by the presence of thick mill scale but are more often associated with improper procedures or techniques. Excessively low travel speeds may cause the molten puddle to roll ahead of the arc, resulting in overlap. Often, welds with overlap can be corrected by carefully removing the overlapped weld metal by grinding. While shown in a groove weld in Figure 9-3, overlap can occur in fillet welds as well.

Cracks

A crack is "a fracture-type discontinuity characterized by a sharp tip and a high ratio of length and width to opening displacement" (AWS, 2010d). Cracking is covered extensively in Chapter 6 of this Guide.

Lamellar Tearing

A lamellar tear is "a subsurface terrace and step-like crack in the base metal with a basic orientation parallel to the wrought surface created by tensile stresses in the through-thickness direction of the base metals weakened by the presence of small disperse, planar-shaped, nonmetallic inclusions parallel to the metal surface" (AWS, 2010d). The topic is covered extensively in Section 6.4 of this Guide.

Laminations and Delaminations

Laminations and delaminations are planar base metal discontinuities lying parallel to the surface of the steel. The term *lamination* is used when there is essentially no gap between the two surfaces of the planar discontinuity. When the surfaces open up and a gap is formed, the term *delamination* is used. Laminations and delaminations typically occur in the mid-thickness of the steel, whereas lamellar tearing occurs during welding and is usually located just outside the HAZ, generally within ¼ in. (6 mm) of the steel surface. Laminations may be detected when the material is thermally cut. Nondestructive testing can be used to detect laminations. ASTM A435 *Standard Specification for Straight-Beam Ultrasonic Examination of Steel Plates* (ASTM, 2016) and ASTM A898 *Standard Specification for Straight Beam Ultrasonic Examination of Rolled Steel Structural Shapes* (ASTM, 2017b) provide guidance on inspection methods used to detect laminations or delaminations.

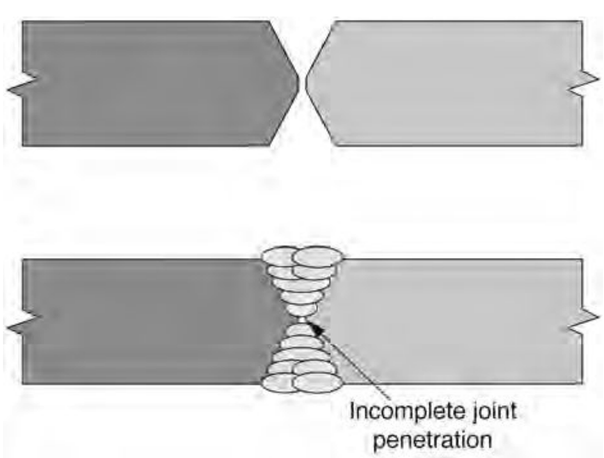

Fig. 9-2. Incomplete joint penetration.

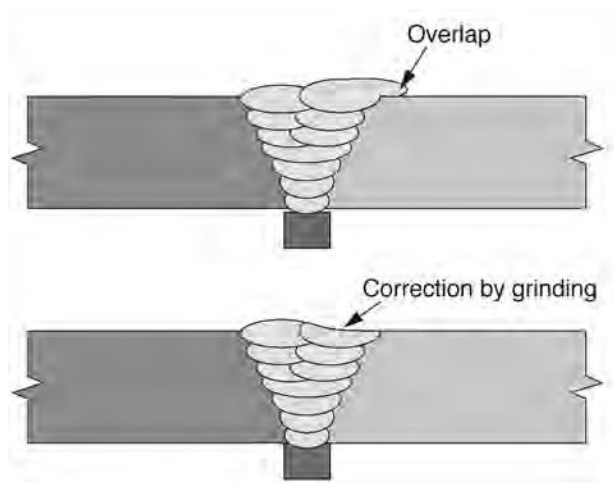

Fig. 9-3. Overlap.

Plates or shapes that contain laminations and delaminations may be acceptable for service when the discontinuity is parallel to the stress field. Conversely, when the discontinuity is perpendicular to the stress field, careful investigation into the extent of such planar discontinuities is warranted; extensive discontinuities under such conditions justify rejection of the material. When laminations or delaminations are discovered early in the fabrication process, the material can be rejected with minimal consequence. Unfortunately, such indications are often discovered late in the fabrication or erection sequence, and the suitability of the fabricated material should be made on a case-by-case basis.

9.5.2 Volumetric Discontinuities

Volumetric discontinuities are three-dimensional imperfections located in and around the weld. Some volumetric discontinuities have rounded or blunted edges that created a less severe stress raiser than the crack-like edges of planar discontinuities. As such, AWS D1.1 permits some volumetric discontinuities to be accepted and left uncorrected. This acceptance depends on the type of weld, type of loading, size, frequency, spacing of the discontinuities, and other factors.

Undercut

Undercut is "a groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal" (AWS, 2010d), as shown in Figure 9-4. AWS D1.1, Table 6.1, provides acceptable limits for undercut as a function of the length, depth, orientation, and type of loading (static and cyclic). Excessive undercut is usually associated with poor welding procedures or techniques, such as improper electrode placement, high arc voltage, or the use of improper welding consumables.

Minor undercut may be repaired by careful grinding to reduce any notch-like feature of the undercut as shown in Figure 9-4(b). While not specifically endorsed by AWS D1.1, the concept is similar to repair of small edge discontinuities as addressed in clause 5.14.8.4. The loss of cross section should not exceed 2%. Undercut may also be repaired by welding. Because only a small amount of weld metal is required to fill the undercut void, there is a tendency to make very small repair welds that may introduce additional problems such as cracking or hardening in the HAZ, as shown in Figure 9-4(c). Repairs that involve welding should utilize welding procedures that comply with production welding requirements, including preheat temperatures and adequate welding heat input levels as illustrated in Figure 9-4(d). When undercut is properly repaired by welding, the repaired region inevitably has a weld that is substantially larger than the required size.

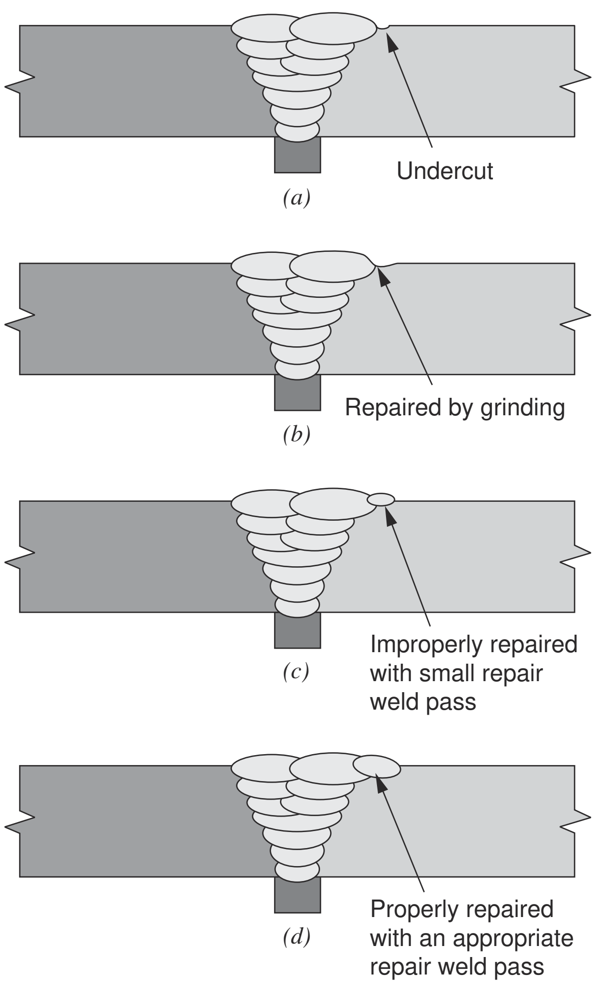

Fig. 9-4. Undercut and proper repair methods.

Porosity

Porosity refers to "cavity-type discontinuities formed by gas entrapment during solidification…" (AWS, 2010d). Porosity assumes the form of spherical or cylindrical cavities in the weld and is shown in Figure 9-5. Porosity may be surface-breaking or may be internal to the weld.

Porosity occurs as the result of inadequate shielding of the weld metal or excessive contamination of the weld joint, or both. The products used for shielding weld deposits (gases, slags) must be of appropriate quality, properly stored, and delivered at the correct rate to provide adequate shielding. Excessive surface contamination from oil, moisture, rust or mill scale increases the demand for shielding. Porosity can be minimized by providing proper shielding and ensuring joint cleanliness. For shielded metal arc welding (SMAW), long arc lengths can cause porosity as can electrodes with wet coatings. For gas metal arc welding (GMAW) and gas-shielded flux-cored arc welding (FCAW-G), leaks in the shielding gas hoses can contaminate the shielding gas and lead to porosity. Inadequate shielding gas flow rates or disruption of the gas shield can also cause porosity. For self-shielded flux-cored arc welding (FCAW-S), excessive arc voltages or short electrode extensions can cause porosity. For submerged arc welding (SAW), a common cause of porosity is contaminated flux, particularly when flux is reclaimed.

To repair welds with excessive porosity, the weld metal that contains the porosity should be removed, and that portion of the weld replaced. AWS D1.1, Table 6.1, defines acceptable limits for porosity as a function of its type, size, distribution, and type of loading.

Slag Intrusions

A slag intrusion is "a discontinuity consisting of slag in weld metal or along the weld interface" (AWS, 2010d), as shown in Figure 9-6. Slag intrusions are often referred to as slag inclusions. Slag intrusions are generally attributed to slag from previous weld passes that was not completely removed before subsequent passes were applied. Slag intrusions in completed welds are typically detected by nondestructive testing, not visual inspection.

With proper weld joint designs, welding procedures, and techniques, slag can be easily removed from the joint, mitigating the formation of slag intrusions. However, when welding conditions are suboptimal, slag removal may be difficult. The typical location for trapped slag is at weld toes. Careful grinding of weld toes before the application of a subsequent weld pass is effective in minimizing the possibility of slag intrusions.

Excessive Concavity

Concavity refers to the profile of the surface of the weld as shown in Figure 9-7. Concavity is considered excessive when it exceeds the limits in AWS D1.1, clause 5.23, or

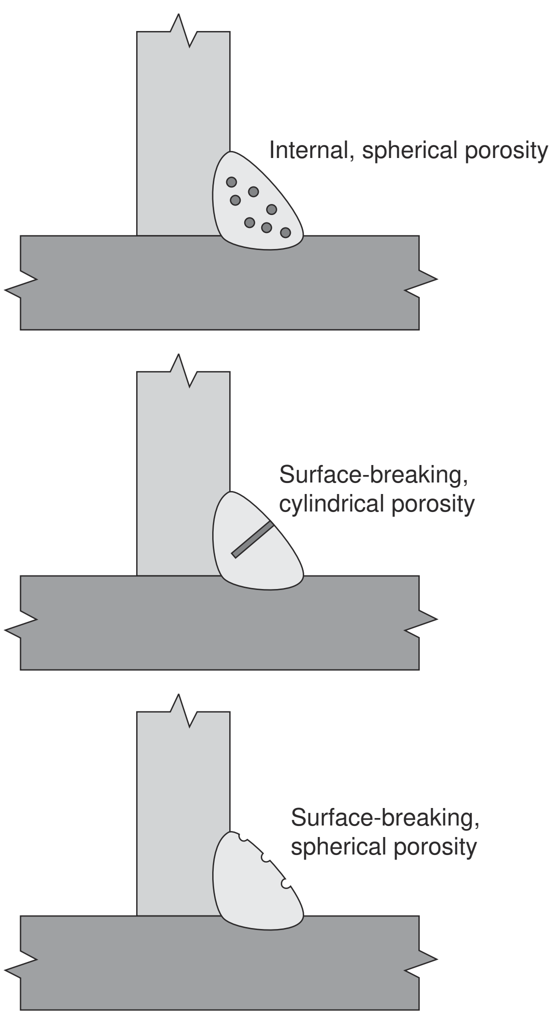

Fig. 9-5. Types of porosity.

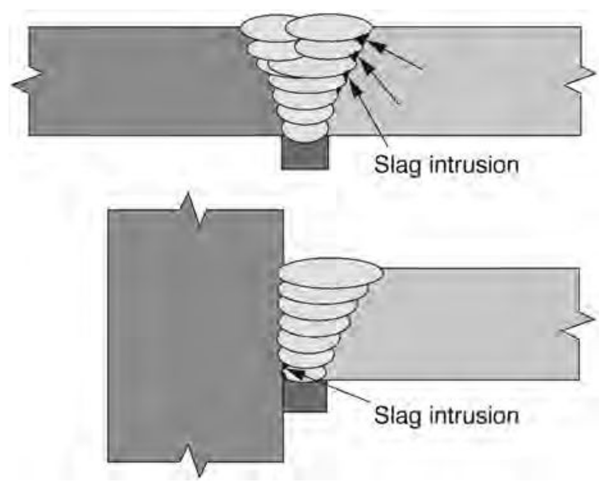

Fig. 9-6. Slag intrusions.

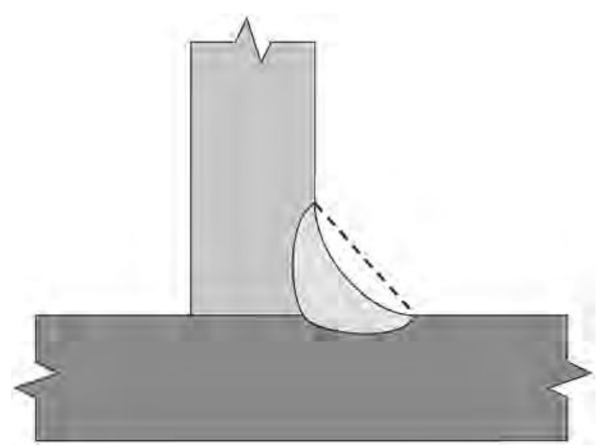

Fig. 9-7. Excessive concavity.

when the required weld throat is not achieved. Excessive concavity can lead to centerline cracking (see Section 6.3.1 of this Guide), but cracking is a separate issue from concavity. Excessive concavity is typically caused by an improper welding procedure or welding technique. Reducing the welding current and voltage where applicable will usually remedy this problem. The primary concern with a concave weld is that the throat may be inadequate. Concave weld surfaces with adequate throats are not a problem. Inadequate weld throats created by excessive concavity are easily fixed by simply depositing another weld pass on the concave surface.

Excessive Convexity

Convexity is considered excessive when it exceeds the limits presented in AWS D1.1, clause 5.23. As shown in Figure 9-8, excessive convexity wastes weld metal, and may increase the stress raiser at the weld toe if the stress field is perpendicular to the weld axis. In most cases for static building applications, excessive convexity is primarily a visual concern only. Improper procedures and technique are generally responsible for this condition.

For welds made with excessive convexity, corrective measures typically involve removal of the excessive metal by grinding. However, removal of excessive weld metal from the face, while correcting the excessive convexity issue, will do nothing to correct for the stress raiser at the weld toe as shown in Figure 9-9. If improvement of the weld toe is necessary, the toe region should be ground to smoothly transition from the base metal to the weld, and such measures are typically justified only when the structure is subject to cyclic loading.

Inadequate Weld Size

Welds may be too short or too small for a given application. Undersized welds are typically indicative of workmanship or procedural problems, often resulting from travel speeds that are too high. AWS D1.1, Table 6.1, permits welds to be undersized within certain limits and at certain locations. Undersized welds are repaired by depositing additional metal to the undersized weld. The repair weld should be of a size and length that is conducive to good practice.

Underfilled Weld Craters

An underfilled weld crater is a concave depression at the end of the weld, and in this localized area the weld throat is reduced. Underfilled weld craters are typically due to workmanship or procedural problems. Normally, a slight pause at the end of a weld can fill a weld crater. AWS D1.1, Table 6.1, requires all weld craters to be filled, except for at the ends of intermittent fillet welds where the required weld length is achieved without a crater.

The two potential detrimental effects of underfilled weld craters are development of cracks with a star-like pattern or an inadequate weld throat. Underfilled weld craters can be

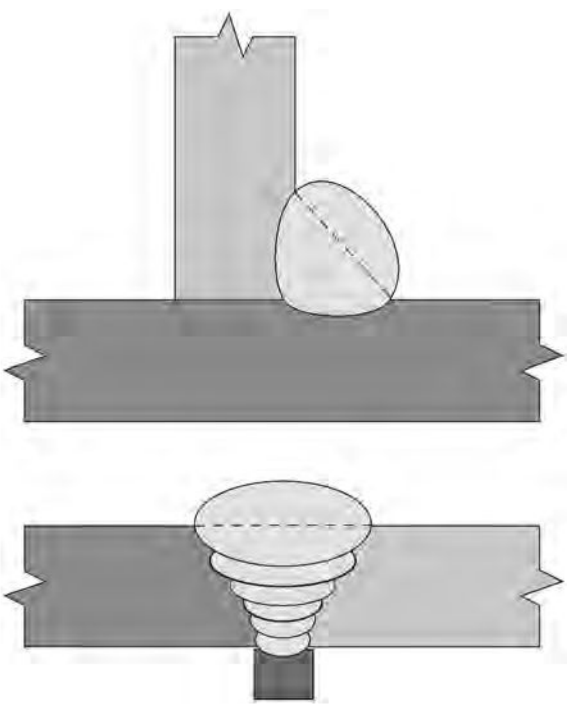

Fig. 9-8. Excessive convexity.

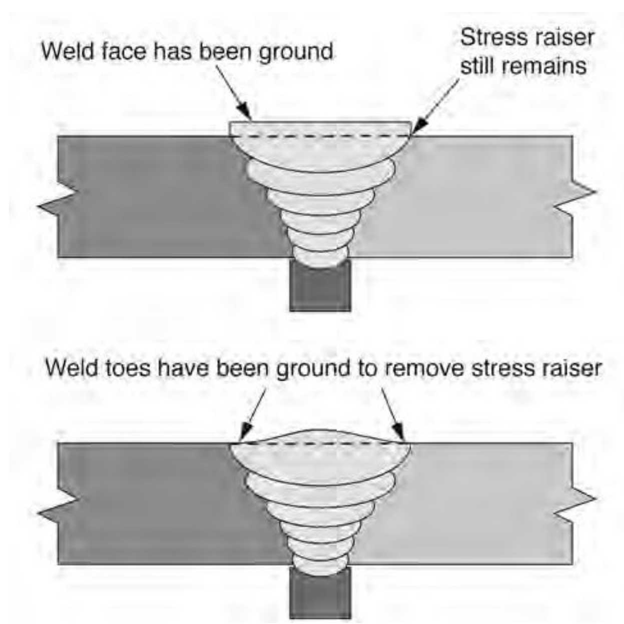

Fig. 9-9. Repair of excessive convexity.

repaired by depositing additional metal in the crater. However, simply applying a localized spot of metal in the crater is likely to do more harm than good. Welds with underfilled but uncracked weld craters may be suitable for service in some situations, but in others, the end of the weld may be the most severely loaded portion of the weld. Crater cracks should be repaired by removal of the cracked portion by grinding and replacing the removed material with sound metal.

Spatter

Spatter is defined as "the metal particles expelled during fusion welding that do not form part of the weld" (AWS, 2010d). Spatter consists of the roughly spherical particles of molten weld metal that fuse to the base metal outside the weld joint or to the weld metal surface. Spatter is generally not considered to be harmful to the performance of welded connections. However, excessive spatter may inhibit proper ultrasonic testing, is generally unacceptable for architecturally exposed structural steel (AESS) projects, and may affect the integrity of coating systems. In all cases, excessive spatter is indicative of less than optimum welding conditions and suggests that the welding consumables and/or welding procedures may need to be adjusted.

Loose spatter is easily removed by scraping, while more tightly adhering spatter can be chiseled or ground off. AWS D1.1, clause 5.29.2, puts no limit on spatter, except that it cannot interfere with NDT. For AESS projects, spatter removal is typically required.

Arc Strikes

An arc strike is "a discontinuity resulting from an arc, consisting of any localized melted metal, heat-affected metal, or change in the surface profile of any metal object" (AWS, 2010d). Arc strikes are caused by inadvertent arcing between electrically charged elements of the welding circuit and the base metal. Welding arcs that are initiated outside the joint leave behind these arc strikes. SMAW is particularly susceptible to creating arc strikes, because the electrode holder is electrically hot (i.e., energized) when not welding. For any of the welding processes, arcing of work clamps to the base metal can cause arc strikes, and welding cables with damaged insulation can result in arc strikes. Welding cables should be insulated and in good condition. Proper welding practices minimize arc strikes.

Arc strikes should be avoided; when arc strikes do cause cracks or blemishes, AWS D1.1, clause 5.28, requires that they be ground smooth and checked to ensure soundness. Removal of the affected metal by grinding will eliminate any potential harm from arc strikes. This includes the formerly melted metal as well as any hardened HAZ.

9.6 METALLURGICAL DEFICIENCIES

Welds are expected to have certain mechanical properties and, to some extent, certain chemical compositions. Failure of welds to achieve these conditions can be described as metallurgical deficiencies. All of the discontinuities discussed in Section 9.5 of this Guide are detectable, although some can be identified only with destructive or nondestructive testing. Unfortunately, there are no practical ways to directly verify that the deposited weld metal will have all the required metallurgical properties. Fortunately, by identifying and controlling variables that affect the properties of deposited welds, the process by which the weld is made can be controlled and in turn, the weld metal metallurgical properties can be controlled.

The mechanical properties of a weld are primarily dependent on the chemical composition of the weld deposit, the rate of cooling experienced by the weld, and any subsequent thermal treatment the weld receives. Control of the chemical composition of the weld depends on two primary elements: welding on base metal of a known composition and using the proper filler metals. Cooling rates depend on the amount of thermal energy introduced into the joint (preheat temperature, heat input, etc.) and how much material is available to conduct the energy away (material thicknesses and configurations). While there are many factors involved these factors can all be monitored and controlled easily.

For structural steel applications, the chemical composition of the deposited weld metal is not a major concern, with the exception of welds on weathering steel (see Section 5.4.1 of this Guide). Even in this case, the precise chemical composition is not critical. Mechanical properties pose the greater concern for structural applications. The required yield and tensile strengths are routinely achieved unless actual welding parameters deviate significantly from the prescribed values or incorrect electrodes are used. Fracture toughness, typically measured with the CVN specimen, is perhaps the most variable mechanical property in deposited weld metal. For applications where welds are expected to exhibit certain levels of fracture toughness, the use of proper welding parameters is even more important. Particular focus on those factors that affect weld cooling rates such as preheat, interpass temperature and heat input, is warranted in such situations.

The primary means used to ensure weld quality is through control of the process of welding. In this context, process does not refer to the welding process (i.e., SMAW, FCAW), but the start-to-finish control of all the variables that may affect the quality of the weld. These controls include the inspection checklist items as contained in AISC *Specification* Tables N5.4-1, N5.4-2 and N5.4-3.

9.7 TYPES OF BASE METAL DISCONTINUITIES

9.7.1 Base Metal Quality

The quality of the steel used in welded construction is typically governed by ASTM A6/A6M, where Part 9.1 requires the structural steel to be "free of injurious defects and shall have a workmanlike finish" (ASTM, 2016). The steel is permitted to have "noninjurious surface or internal imperfections, or both…" according to ASTM A6/A6M, Note 4. These conditions apply to the steel in the as-received condition. Cracks may form during bending, shearing and thermal cutting of the steel; such cracks are not cause for material rejection, although the material may no longer be suitable for service. Grinding and blasting may reveal surface imperfections; injurious defects revealed in this case would constitute grounds for material rejection. Of course, the operative term, *injurious*, is subject to interpretation. It should be noted that hot-rolled steel, particularly when finely ground or polished, will contain a variety of imperfections; noninjurious surface imperfections should be expected.

ASTM prescribes conditions for repairs that can be made at the mill, including grinding and repair welding. Shallow imperfections can be corrected by grinding, providing the depth does not exceed prescribed limits. Repair by welding is permitted by ASTM A6/A6M, Parts 9.2 to 9.4, for deeper imperfections that do not exceed specified limits. Welding requirements are also specified in ASTM A6/A6M, Part 9.5. AWS D1.1 does not impose any additional base metal quality requirements beyond those specified for the steel in ASTM.

AWS D1.1, clause 5.14.2, stipulates that welds are not permitted to be made on "…fins, tears, cracks, slag, or other base metal defects as defined in the base metal specifications." When a defect in the steel is welded upon, the expansion and contraction that will occur during welding will likely exacerbate the defect that was present before welding.

Suspect areas on the surface of the steel can be easily evaluated by localized grinding. The edge of the imperfection is readily detected while grinding because the thin edge will heat and may turn red in color; after grinding, the edge will usually be discolored as a result of the oxidation of the heated metal.

Larger discontinuities can be removed and repaired by welding. Limits to the extent to which such repairs can be made are contained in AWS D1.1, clause 5.14.5. Welded repairs to correct for base metal defects are addressed in Section 15.8 of this Guide.

9.7.2 Quality of Thermally Cut Edges

Although thermally cut edges can be grouped into two major categories—edges that will become part of a welded connection and those that are simply the edge of a part—the quality requirements for both types of thermally cut edges are the same.

Weld access holes and reduced beam section (RBS) cuts are specific examples of thermally cut surfaces that are not welded upon; these applications are addressed in Sections 4.4.2, 11.8.1 and 11.8.2 of this Guide.

The quality of cut edges is governed by surface roughness requirements and the size of inclusions that might be revealed on the cut edge. The roughness requirements are listed in AWS D1.1, clause 5.14.8.3. Reference is made to C4.1-77, which is a plastic sample with replications of four thermally cut surfaces labeled 1, 2, 3 or 4, with 1 being the roughest surface. While visual comparison is discussed in the code, tactile comparison is the common practice. Properly prepared thermally cut edges are not required to be ground according to AWS D1.1, clause 2.17.4. Cut surfaces may have occasional notches or gouges. AWS D1.1, clause 5.14.8.4, provides three categories for dealing with gouges:

- Gouges less than 3⁄16 in. (5 mm) are to be removed by grinding or machining.
- Gouges exceeding 3⁄16 in. (5 mm) may be repaired by grinding if the nominal cross section is not reduced by more than 2%. Such grinding is to be faired to the original surface by a slope of not less than 1 in 10.
- Gouges that require welding require the approval of the engineer. AISC *Specification* Section M2.2 permits repair by welding to gouges deeper than 3⁄16 in. (5 mm) without requiring engineer approval.

When steel is severed, the cut edge may reveal the presence of inclusions or laminations, referred to as mill induced discontinuities. These discontinuities are essentially planar and parallel to the surface of the steel; as a result, they will appear as a line on the cut edge. AWS D1.1, Table 5.4, defines how edge discontinuities are to be handled. Depending on the length of the discontinuity, some are accepted as is without corrections, others are repaired by removal by grinding only, while others are ground and repaired by welding. When edge indications are long and deep, ultrasonic testing of the plate is required to determine the extent of the discontinuity.

An important note in AWS D1.1, clause 5.14.5.2, deals with repairs to discontinuities discovered on cut edges, stating that the provisions listed "…may not be adequate in cases of tensile loads applied through the thickness of the material." In such loading cases, further investigation into the extent of lamellar indications is warranted.

AESS columns with welded cast steel nodes at a university project in Toronto.

Chapter 10
Weld Inspection

10.1 INTRODUCTION

Welds are inspected to ensure that they comply with the requirements of a given specification. Weld inspection fits into two broad categories: destructive and nondestructive. Destructive testing typically involves machining test specimens from a weldment, applying a force, and measuring the response of the test specimen to the force; after this, the weldment is no longer useful for the intended service. Destructive testing is applied to welding procedure qualification test plates, and may include tensile testing, Charpy V-notch (CVN) testing, and bend tests. In contrast to destructive testing, nondestructive testing (NDT) allows for examination of the weld without affecting the ability of the weld to function in the intended service.

Welder qualification testing and welding procedure qualification testing as prescribed in AWS D1.1 have both nondestructive and destructive testing requirements. For production welds, the AISC *Specification* (AISC, 2016d) prescribes both visual inspection requirements and nondestructive tests. Connection configurations designed to resist seismic loading may be subject to destructive testing in laboratory tests before they are used on an actual project. Visual inspection is generally considered to be a form of nondestructive testing, but for this chapter, visual inspection will be discussed separately from NDT.

Many NDT methods exist, but for structural steel inspection only a few are commonly used; these methods will be discussed in this chapter.

10.2 VISUAL INSPECTION

Visual inspection (VT), also called visual testing or visual examination "…is a nondestructive method whereby a weldment, the related base metal, and particular phases of welding may be evaluated in accordance with applicable requirements. All visual examination methods require the use of eyesight to evaluate the conditions which are present; hence, the term visual examination" (AWS, 2015b). As implied by the term, VT can only detect what can be visually observed. For completed welds, this limits the method to detection of discontinuities that are on the surface or are surface breaking. This has caused some to discount the value of VT. However, the power of VT lies in the ability to examine particular phases of welding. Alternately stated, VT allows for examination of the whole process of welding from start to finish. AWS B1.11, *Guide for the Visual Examination of Welds* (AWS, 2015b), provides a useful expansion on the topic of VT.

AWS D1.1, clause 6.9, requires that all welds are visually inspected. This includes welds that are subject to other nondestructive testing as well, and VT should be performed before NDT. Ironically, it is common to find welds that meet NDT requirements, which focus on internal quality, and yet fail visual acceptance criteria that is solely focused on surface conditions. When properly performed, VT is the most powerful inspection methodology. VT is the only inspection method that can actually improve the quality of a given weld. For example, visual inspection of the weld joint preparation and the adequacy of the root opening dimension can ensure that conditions conducive to obtaining good fusion are present before welding begins, minimizing the probability of incomplete fusion in the completed weld.

To be effective, visual inspection must take place before, during and after welding. The before and during aspects are often overlooked. Fortunately, with the incorporation of Chapter N into the AISC *Specification,* the concepts of before, during and after inspection are duly emphasized. Chapter N contains three tables that outline specific tasks that are to be performed: Table N5.4-1 for tasks to be done before welding; Table N5.4-2 for tasks to be done during welding; and Table N5.4-3 for tasks to be done after welding. Most of the tasks involve visual inspection and most are assigned to the quality control inspector (QCI), the individual designated to perform quality control inspection tasks for the fabricator or erector.

While specific VT responsibilities are assigned to both the quality control (QC) and quality assurance (QA) inspectors, everyone associated with welding on a project can, and should, participate in VT, including welders and foremen. With VT, minor irregularities can be detected and corrected during the fabrication process, precluding the need for more expensive and complicated repairs after the weld is complete.

"Before" welding tasks include verifying that welders are qualified, that WPS are available, that the joint is properly fit, and that the welding equipment is suitable for the application. "During" welding tasks include adhering to the WPS, including preheat requirements, cleaning between weld passes, and confirming the quality of each pass. "After" welding tasks include checking the weld size and examining the weld for cracks, porosity and undercut. These examples are illustrative and not exhaustive; the AISC *Specification* and AWS D1.1 provide a comprehensive list of required VT tasks.

VT relies on eyesight, and two implications follow: The inspector's vision (with correction, if necessary) must be good, and there must be sufficient light present. AWS D1.1, clause 6.1.4.4, requires eye examinations for inspectors and simple flashlights can be used to provide illumination in dimly lit situations.

10.3 NONDESTRUCTIVE TESTING—GENERAL

NDT, which may also be called nondestructive examination (NDE), is "the process of determining acceptability of a material or a component in accordance with established criteria without impairing its future usefulness" (AWS, 2015c). While NDT is an important element of many quality programs, it cannot replace in-process or after-the-fact visual inspection. Before NDT is performed, AWS D1.1, clause 6.9, requires that the welds first meet visual acceptance criteria (AWS, 2015c). Because of the diversity of projects that can be governed by AWS D1.1, it is impossible for a single document to specify all appropriate inspection requirements for all projects, including the extent and type of NDT to be performed, acceptance criteria, and who is responsible for various inspection tasks. AWS D1.1, therefore, relies on the engineer to specify such NDT requirements. In contrast, the AISC *Specification* has a more limited scope of applications, and since 2010, Chapter N has codified NDT requirements.

A variety of NDT methods are available to inspect welds, each with advantages and limitations. The four inspection methods most commonly used along with VT to inspect structural steel welds are discussed in the following sections.

10.4 PENETRANT TESTING

Penetrant testing (PT) is an NDT method that relies on the ability of low viscosity liquid (i.e., the penetrant) to be drawn into a void or crevice by capillary action and be retained while the excessive liquid is removed; a developer is used to reveal locations where the penetrant has been held, as shown in Figure 10-1. The process is also known as liquid penetrant testing, dye penetrant testing, or simply dye-pen. PT can detect only surface-breaking discontinuities. Two types of penetrants are available: visible dye, meaning it can be seen in ambient light, or fluorescent, requiring the use of an ultraviolet light. Fluorescent penetrants are more sensitive to visual detection, thus allowing for a more detailed inspection; however, the part being inspected must be in a darkened room or enclosure where it can be viewed with an ultraviolet light. For structural steel applications, therefore, visible penetrants are typically used. Practices for PT are prescribed in ASTM E165 *Standard Practice for Liquid Penetrant Examination for General Industry* (ASTM, 2016) and AWS D1.1, clause 6.10. In the 2016 AISC *Specification*, PT is not prescribed for any application. Prior to the 2016 edition, the AISC *Specification* required either magnetic particle testing or penetrant testing of weld access holes in heavy rolled sections and heavy built-up shapes; this required NDT was deleted in 2016.

PT enables detection of small surface-breaking discontinuities that might be overlooked or undetectable with visual inspection. The required materials for PT are inexpensive and the basic training required to use the process is minimal. PT can be used on magnetic or nonmagnetic materials; it is often the inspection method of choice for nonmagnetic stainless steel or aluminum. When a record of PT inspection is desired, the inspected area can be photographed.

Despite the simplicity of the NDT process, PT must be used correctly to be effective. The part must be relatively clean before inspection; if the voids are filled with

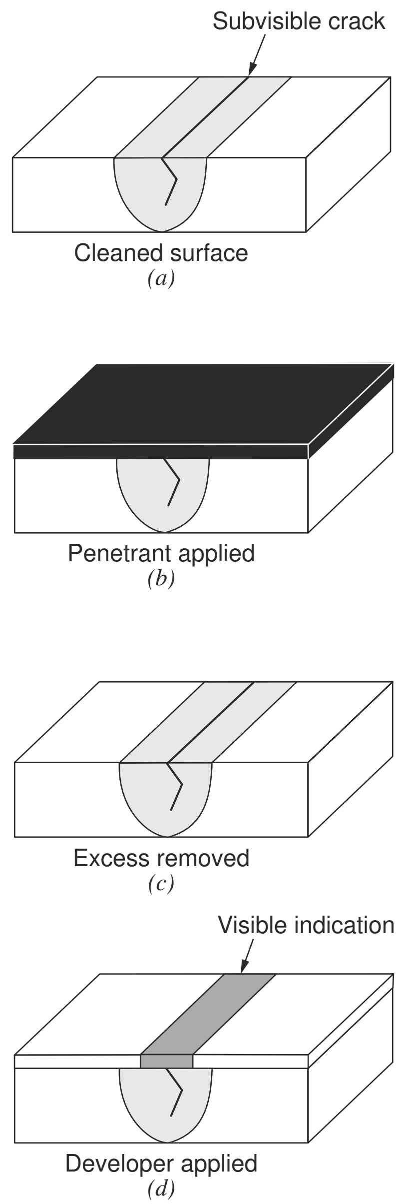

Fig. 10-1. Penetrant testing: (a) cleaning; (b) penetrant application; (c) removal of excess penetrant; (d) application of developer.