SCWI Study Guide
NONDESTRUCTIVE INSPECTION OF WELDS

Part 1—INTRODUCTION

This section of the Senior Welding Inspection Technology Manual is based on requirements set out in the American Welding Society (AWS) document, QC1-96. Subsection 5 deals with "Education and Experience Requirements". Paragraph 5.1.8 specifies that applicants for certification as a SCWI, among other qualifications, "Shall be familiar with, understand, and be capable of specifying, planning, and/or supervising personnel performing the following activities:"

VT	UT	RT	*QA Audits
MT	PT	AET	*QA Surveillance
LT	ET		*QA Procedures

The first topic of Module 4 of this program is a review of visual inspection (VT) from the perspective of the SCWI. Then, the other listed NDE methods are considered. The QA functions ('starred' {*}above) have already been dealt with in Module 2 of this program.

While the mechanics of each NDE method will be reviewed, the principal thrust is the development, implementation and supervision of the procedures. It is not a requirement that the SCWI be able to perform NDE. However, it is essential the SCWI has a sound grasp of the principles and practices pertaining to each of the above methods.

Further, it is vital to have a thorough knowledge of the applicable variables and their influence on the result. Environmental and safety considerations are also within the responsibilities of the SCWI. A copy of ANSI/ASC Z49.1, Safety in Welding, Cutting and Allied Processes should be a safety reference for each SCWI.

Certain abbreviations will be used throughout Module 4. In most instances, the whole term or expression will be spelled out and the abbreviation shown in parenthesis following the first use of the term.

Terms and Definitions

There are certain terms and definitions, over and beyond those of AWS A3.0, Standard Welding Terms and Definitions that should be clearly understood. These include:

- NDE Method
- NDE Technique
- NDE Procedure
- NDE Instruction
- NDE Report
- NDE Overview

NDE Method

A discipline applying a physical principle used in nondestructive examinations. For instance, radiographic testing, the basic elements of which are shown in Figure 4.1.1.

NDE Technique

A specified way of utilizing an NDE method. By way of an example, radiographic fluoroscopy, a diagram of which is shown in Figure 4.1.2.

NDE Procedure

A written description of all essential parameters and precautions to be observed in applying an NDE technique to a specific test, in accordance with requirements of an established code, standard or specification. AWS D1.1-96, in Section 6, for instance, gives the requirements for each of the four NDE methods most frequently used for welded structures. The presentation of requirements varies with the method. For MT and PT, reference is made to ASTM standards, E709 and E165, respectively. For UT, very detailed instructions as to equipment, calibration, testing and evaluations of echo signals are given.

NDE Instruction

A written description of the precise steps to be followed in examining/testing to an established standard, code, specification or NDE Procedure.

Within each NDE method, there are a number of variations. For instance, Figure 4.1.3 shows an application of ultrasonic testing known as immersion testing.

While such a technique is unlikely to be applied extensively in examining welded structures, it is used in other fields. It is apparent that variables applicable to welding-related work may not always be identical to those used in other industrial sectors.

An NDE instruction typically details:

1. Purpose, application and scope
2. List of equipment (and consumables)
3. Equipment specifications, as applicable
4. Qualification of equipment
5. Qualifications of test personnel
6. Calibration of test equipment
7. Details of test/s required
8. Conformance/nonconformance criteria
9. Recording, reporting test results
10. General provisions also applicable

A sample NDE Instruction Sheet is given as Form A in Section 4.3. This also includes an example of a completed Form A for PT. It can be seen that considerable detail is given. The object of an NDE ‘instruction’ is to provide a step-by-step guide to the NDE operator. On the job circumstances can be such that some facet of a test is overlooked. The NDE instruction also acts as a check list and gives protection against the occurrence of this possibility.

An additional term within the broad field of NDE is “Sector”. It is the particular section of industry or technology where an NDE technique is used. In the present context, the consideration is concerned with principles. This is primarily in connection with welds and the heat affected zone (HAZ). While the adjacent base metal is just as important as the weld areas, the type of inspection and NDE technique required will likely differ.

Obviously, instruction requirements for a liquid-carrying pipeline will probably differ from those for a tubular structure. While the conformance requirements will change, and the NDE procedures may be different, the principles for each NDE method remain constant.

Test details have to be adjusted to meet the requirements imposed by welding. Ultrasonic testing of castings, for instance, uses the same machine, but the transducers will be different. One task of the SCWI is to ensure these differences are recognized.

The clear distinction between an NDE Procedure and an NDE Instruction should be understood. An NDE Procedure may, in one sense, be considered as analogous to the PQR, from which any number of WPSs, each for a specific task, can be drawn. The NDE Instruction applies to the testing of a specific item, or group of like items. The NDE Procedure specifies the broad principle of a test method, as applied in the establishment under consideration.

NDE Report

The NDE report typically gives the specific details for each of the above headings noted in the Instructions. If the equipment required was a “Pulse echo ultrasonic testing machine with transducers suitable for examining welds in HSLA steels”, the report will give the machine
brand, model and serial number.

A sample and completed NDE Report Form are shown in Section 4.3. Note the considerable detail in the Report.

NDE Overview

NDE as a whole may be classified in several different ways. The most common is that
pertaining to surface/subsurface capabilities. VT and PT are useful only for surface examinations. RT and UT, although having the capability of detecting surface-breaking discontinuities, are generally used for subsurface detection only.

MT and RT methods are highly orientation
sensitive. They may not reveal the presence of particular discontinuities: Figure 4.1.4, and Figure 4.1.5, illustrate this limitation.

Both ET and MT have, under appropriate conditions, some subsurface capabilities. However, both are more usually concerned with the surfaces of the materials being examined. ET has some very specific areas of application in the field of welding.

For instance, in the production of seam-welded pipe or of wire used as a welding consumable, ET is able to detect even the smallest of surface or near-subsurface discontinuities. This is illustrated in Figure 4.1.6, which shows an application of ET.

AET and LT (see Figure 4.1.7) are used to detect and quantify specific discontinuities, located either on the surface or within the material of the component.

Acoustic Emission Testing may be used in certain applications during welding fabrication. However, its main use is in connection with the in-service monitoring of containers, machines and structures.

ROLE OF THE SCWI IN NDE

Inspection may be concerned with new fabrications. Alternatively, it may be centered on existing structures such as in-service inspections, usually associated with maintenance, repair or reconstruction. In either case, the SCWI will possibly be involved in the selection of the examination method(s). Hence, a good knowledge of the advantages and limitations of the respective NDE techniques are essential.

Certain characteristics of NDE methods are process-specific, such as the directionality of radiography. Others tend to be context-specific. If it is required to check the back gouging of a preheated carbon steel weld, MT, rather than PT, is likely to be the NDE process of choice. However, if the base metal was an austenitic stainless steel, a different set of rules apply. Several charts are available to show areas of best application for the NDE methods.

The need to make these choices frequently comes about because purchasers do not always have a full understanding of what is required. Ideally, purchasers would specify the NDE method(s) to be used. In terms of quality, reference would desirably be made to published or specially developed codes, standards or specifications. The supplier's obligations would then be clear, unequivocal and not subject to interpretation.

The worst case is where no quality standards are specified. This appears to be advantageous to suppliers of welded products. However, this is rarely the case.

The usual scenario is that someone in the purchaser's organization belatedly sees the omission. This usually becomes known after work has commenced, typically when the supplier is financially committed. Sales people are often involved but rely on the possession of an order. The purchaser withholds payment and the supplier has a potential loss on the horizon; a dissatisfied purchaser and an angry supplier. Clear, up front, fully defined quality requirements and how they are to be achieved and assured is a primary responsibility of the SCWI.

In other instances, purchase documents only detail the 'quality' level required to be achieved, often in qualitative terms. In this context, 'quality' is not always construed as "conformance to specification". An effective quality management system will signal this shortcoming.

Action must be taken, before the event, to obtain purchaser approval for the use of an appropriate method and technique. This, including the preparatory work and the negotiations required, will generally be a SCWI task.

The quality of welds and welding is a general responsibility. Assurance that the purchaser-specified quality has been achieved is a particular responsibility of the welding inspector. It is the intent and purpose of this section to outline and review the steps necessary to give that assurance.

In Module 4 the basic elements of each method are covered in general as well as the specifics. Visual inspection (VT) is the primary NDE method.

When required, VT is supported by other NDE methods. It will be shown that visual inspection is an on-going process. It is common to all activities when welded product quality is to be assured. It is a requirement of all codes and specifications covering weld quality.

Nondestructive examination (NDE) comprises a number of processes. Certain NDE processes are employed to extend the range of visual inspection by detecting subsurface discontinuities. These, and yet other processes, are available that may be used to monitor the condition of welds and welded structures in day-to-day service.

WHAT IS 'QUALITY'

One of the most important considerations concerning any type of inspection is the term 'quality'. Quality is defined as 'conformance to specification'. To assure quality, it is necessary for welding inspectors at all levels to be able to read, interpret and implement 'specification' provisions.

In this context, the term 'specifications' is construed as codes, standards or instructions relating to product quality. Applicable 'specifications' are, hopefully, referenced in the purchase order (P.O.) or accompanying documents; herein, purchase orders are assumed to be initiated by a purchaser. In AWS D1.1, the purchaser is known as the 'owner'.

CONFORMANCE TO 'SPECIFICATION'

It is evident why ‘codes’ dealing with welded products require welding inspectors to be furnished with unpriced copies of purchase orders. This is the first step in the inspection process; the copy of the purchase order is the initiating document to which all quality requirements must be traceable. Without it, welding inspectors would be unable to give assurance of weld quality conformance. Purchasers have a right to prove that order provisions have been observed.

Therefore, welding inspectors must have the necessary skill to extract all applicable quality provisions from the P.O. specified documents. The importance of this capability is evident from the make up of the American Welding Society (AWS) Welding Inspector certification examinations. Up to one half of the examination is devoted to the extraction of codes and standards requirements.

FUNDAMENTALS OF INSPECTION

Any type of inspection involves comparing the ‘actual’ to the ‘required’. The job attributes that are to conform to purchaser specified requirements are ‘measured’. To ensure accuracy and repeatability, all measuring instruments must be calibrated to a recognized standard. In the United States, national standards for the basic U.S. and SI units have been established (see Section 4.2). These form the basis to which all calibration must be traceable. Other countries have similar standards.

All ‘inspections’ must be carried out in accordance with an established procedure. Procedure suitability should be verified with the owner (purchaser) prior to implementation. Certain codes and standards set out procedures for various activities. The use of these may be mandated (by the owner in the P.O. or elsewhere in a contractual document). Alternatively, and particularly in the case of organizations having a formal quality management system, ‘in-house’ procedures may be used. Typically, a blanket reference to procedures is part of P.O. acceptance. The elements of an NDE procedure are covered below.

For instance, included in the offer there is desirably a provision along the following lines:

“In the absence of a purchaser-required provision to cover any production activity, including inspection, the supplier’s written procedures and standards will be observed”.

To support this action, a copy of applicable procedures or an index of the topics covered, is included in the offer. Doing so often heads off disagreement, which is in keeping with the cost minimization goals of an effective welding inspection and QA system.

INSPECTION APPLICATION PROCEDURES & INSPECTION CONFORMANCE STANDARDS

It is essential the distinctions between ‘inspection application procedures’ and ‘inspection conformance standards’ be clearly understood. The first item is usually applied in the inspection of all or most jobs handled. The second item is often specific to a particular job, or even a part of certain jobs and appears as an ‘instruction’. For instance, conformance requirements for weld undercut are typically different for statically loaded and for cyclically loaded joints.

Inspection application procedures may be documented in almost any form. Some codes give suggested forms, but their use is rarely mandatory. However, the common requirement throughout is that all ‘variables’ are specified. Where appropriate, variables

are given as a range. Since absolute precision is not possible, applicable tolerances must be shown for single values.

Inspection acceptance standards must be realistic; there should be no absolutes. A provision requiring “no crack-like discontinuities” is not a practical requirement. However, a requirement to have “no crack-like discontinuities exceeding 1.5 mm in length” is a realistic expectation.

Likewise, a provision calling for “fully gas- and liquid-tight joints” is a nice thought, but again not capable of achievement. Rather, by way of example only, “a leak rate for gas and liquids not exceeding 10^{-3}Pa · m^3/s may be specified. This could be readily achieved as a normal bubble (leak) test, which is up to 100 times more sensitive (10^{-5} Pa · m^3/s).

INSPECTION PLANS

A formal Inspection Plan is a normal part of any work involving conformance. Inspection Plans may be in a number of forms; ‘Check-lists’ are both commonly used and very effective. However, any format that specifies most or all of the following categories is suitable.

INSPECTION PERSONNEL

The personnel involved in welding inspection must have suitable experience and training to carry out the many different inspections that are required. They must also have a specified level of visual acuity. The necessary abilities include, but are not limited to the following:

- Reviewing & understanding the implications of all the P.O. & related documents that specify or refer in any way to product quality Reading of drawings, both engineering & detail, particularly those where welding is involved
- Ability to prepare Quality Plans embodying the activities required to establish the agreed-upon quality requirements
- Ability to integrate Quality Plan provisions into the job production schedule to minimize productive work interruptions
- Familiarity with welding procedure specification (WPS) & welder performance qualification (WPQ) documentation & their provisions
- Ability to derive all applicable variables & tests required for WPS/WPQ development
- Ability to use both standard and welding related inspection instruments
- Having sufficient knowledge of nondestructive examinations (NDE) methods used as an adjunct to visual welding inspection as will assure appropriate procedures, techniques and reports being used
- Ability to monitor (and desirably, to develop) procedures for repairing or correcting nonconforming product, & to carry out or monitor any additional tests specified and/or required
- Ability to complete inspection reports in all required detail & collect, maintain & collate all documentation & certification that is or may be relevant to establishing that the contractually agreed job quality has been achieved
- Possessing the impartiality and having the ability to accurately represent & present all pertinent information at any level of purchaser or supplier organization

INSPECTION REPORTING

Creation of a ‘paper trail’ requires the generation of records; a record of all the inspections carried out that involve conformance to owner specified requirements is the basic minimum. In-process and internally mandated inspections necessary to establish the conformance of specific attributes should be reported in an appropriate manner.

At the same time, the manufacturer may take such additional steps in keeping with company policy. This may be as comprehensive as a formal ‘Inspection Report’ or as simple as a check mark on a sign-off sheet. A desirable feature of all such reports should be a reference to each ‘procedure’ used, and the applicable conformance requirements.

VISUAL WELDING INSPECTION PRACTICES

A basic reference for the visual inspection of welds and welding is the AWS document B1.11 - Guide for the Visual Inspection of Welds. Bl.ll states that “Adequate drawings and specifications relating to visual inspection should be supplied as part of the contract.”…“Acceptance standards should be clearly understood by manufacturer and buyer before any welding is started.” The importance and significance of these statements is self-evident.

The welding inspector is required to possess certain personal attributes. These include having appropriate visual acuity, inspection experience and training in welding and it’s technology. A CWI, for instance, must have specific visual requirements, as set out in the AWS document, QC-1-96 and previously reviewed in Section 1.1 of this manual.

USE OF CALIBRATED MEASURING AND TEST EQUIPMENT

As discussed in Module 2, the use of only calibrated measuring and test equipment is a QMS provision. This means that all measuring and test equipment used during inspection to determine conformance must be in a state of current calibration. It also means that all such equipment is suitably used and stored to preserve accuracy within the specified limits. The way in which these provisions are implemented would typically be defined in one or more Work Instructions. However, over and above the written instruction, common sense and good engineering practice should be exercised.

Precision and accuracy should not be confused with calibration. Precision is the smallest accurate, repeatable measurement that can be made when using the equipment. With a standard 0-1" micrometer, it is impossible to be precise to within 0.0001". However, if a ‘vernier scale’ has been added, such a degree of precision is readily possible. Wear on the mechanism of the micrometer, however, may be such that it cannot consistently achieve this order of accuracy.

Calibration is used to establish that the accuracy of the subject equipment is within a specified limit with respect to a national standard. This relationship is established either directly, by a NIST-approved laboratory, or indirectly, by comparison to a suitably calibrated standard. Calibration documentation must identify the standard used, both by type and serial number. This assures proper traceability in the event of a problem developing.

SUMMARY

We have reviewed several basic, general concepts. Next, the common NDE Methods will be reviewed in detail.

VISUAL INSPECTION

The details of weld and welding visual inspection at the CWI level have been covered in the AWS CWI training course, Visual Inspection Workshop. However, in all cases, the Visual Inspection is the basic inspection method. The NDE methods mentioned in the following sections of this Module may be considered as adjuncts to the Visual Inspection (VT) process

From the perspective of the SCWI, it is essential that the various techniques employed in Visual Inspection be well and fully understood. As with other methods, visual inspections should be carried out in accordance with a Work Instruction appropriate to the task in hand. For this, a full understanding of the mechanics of visual inspection is a prerequisite. It may also fall to the SCWI to administer or undertake training of personnel in the various methods of visual inspection used within an organization.

VT begins with the inspector. In this way, the selection of materials, joint placement, and weld details can be appropriately influenced. This rationale is derived from the fundamentals of quality management; weld quality assurance is primarily concerned with prevention of problems. Only secondarily is weld quality assurance concerned with 'after the event' inspection.

The aim of any quality system is to assure the purchaser-specified level of quality is achieved. An effective quality system comprises the following five major elements:

- Prevention - by the scheduling of inspections at appropriate stages of job preparation and production.
- Control - through the utilization of formally proven methods, documented in appropriate 'instructions', applied at appropriate stages of production.
- Training - of personnel in the methods and procedures to assure competence and ability in implementation.
- Corrective Action - instituted as soon as any production or system non-conformance or deficiency is detected.
- Audit - regularly scheduled third party reviews of the quality system and the effectiveness of its implementation.

Essentially, quality systems are dynamic and require continuing review. Extensive studies have shown that the single largest cause of weld and weldment deficiencies derive from the product design. The design process typically takes place in four stages:

- Conceptual - determination of the loads associated with achieving the product performance requirements and selection of the materials of construction in terms of properties and load carrying capacity.
- Preliminary - establishment of general shape & selection of suitable materials in terms of composition & form to handle the principal loads.
- Layout - placement of members to transfer loads, location of joints and determination of joint types.
- Detail - detailing of joints, secondary members, weld preparations, etc., required to translate the designer's layout into production details.

Based on the above, the welding inspector is able to make a meaningful contribution at all stages of the design process. The materials must be weldable,

preferably readily weldable. Compromises between strength and weldability are complex. Toughness may also be a deciding factor, particularly in the region of welded joints.

The shape and form of a structure or component should avoid placing welded joints in areas of maximum stress. For example, the sides of a box-like container may be made of four plates, welded at the corners. However, these joints can be quite complex. How do the sides meet? Can a (costly) joint 'preparation' be avoided? Can such joints be readily welded? Can the joints be effectively inspected? Looking into what appears as a very basic design exercise reveals some unexpected problems. Welding inspection must be available to advise designers accordingly.

The load imposed by the product in the container, acting on the corner joints, is augmented by the moment applied by the pressure of the product on the sides. This will be maximum at the square corners, as shown in the lower sketch in Figure 4.2.1.

Figure 4.2.1, upper sketch, shows a suitable alternative to welds at the corners. By bending the ends and moving the joints, the moment is eliminated. Further, four complex corner joints can be replaced by four, or two, or even one, butt joint, which have maximum inspectability. Assembly for welding and in-process root treatment are simplified.

Where multiple members meet at a point, mock-up procedure tests can be carried out to determine weldability and the inspection(s) required to assure joint soundness. Such joints can rarely be effectively inspected after completion.

A list of known 'problem' joints should be maintained by every SCWI. When such joints appear in a design drawing, the designer should be advised accordingly and suitable alternatives suggested.

This principle of proactivity extends through all phases of design. By so doing, up to 50% of all welding problems in production can be avoided. This number of potential problem areas can be further reduced by another 50% by the use of qualified procedures having known reliability.

This assumes the personnel cutting, preparing, and assembling joints for welding are working in accordance with appropriate work instructions. In a physical sense, a welded joint can only be as good as the joint 'prep'. Trained and qualified welders, working to formal procedures, must be supported by trained ironworkers and pipefitters, working in a quality conscious environment.

There is an axiom of quality assurance that applies particularly to welded joint integrity. "When there is insufficient time to do the preparatory work correctly, a much greater amount of time will certainly be expended in putting it right." Added to this, is the interference with production schedules, and worse still, the risk that deficiencies will only be detected when the product is in service. This inevitably affects an organizations good name and reputation.

MEASUREMENT SYSTEMS

In keeping with American Welding Society practice, SI units are used in this module. Table 4.2.1 lists the basic units for SI; Table 4.2.2 lists the derived SI Units; Table 4.2.3 lists the SI Unit prefixes with their symbols and exponential values. AWS has prepared a standard for using the SI system. (ANSI/AWS A1.1-89, Metric Practice Guide for the Welding Industry).

Table 4.2.1 - Base SI Units (per AWS)

Quantity	Name	Symbol
Length	Meter	m
Mass	Kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K

Table 4.2.2 - Derived SI units

Quantity	Unit	Symbol
Frequency	hertz	Hz
Force	newton	N
Pressure (stress)	pascal	Pa
Energy (work)	joule	J
Power	watt	W
Electric potential	volt	V
Electric resistance	ohm	W
Magnetic flux	weber	Wb
Magnetic flux density	tesla	T
Inductance	henry	H
Temperature	° Celsius	°C
Luminous flux	lumen	lm
Illuminance	lux	lx
Radioactivity	becquerel	Bq

Table 4.2.2 - Derived SI units

Quantity	Unit	Symbol
Radiation absorbed dose	gray	Gy
Radiation dose equivalent	sievert	Sv

Table 4.2.3 - SI unit Prefixes

Prefix	Symbol	Multiplier
tera	T *	10^{12}
giga	G *	10^{9}
mega	M *	10^{6}
kilo	k	10^{3}
milli	m	10^{-3}
micro	m	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

*Note use of upper case letters

Derived units are made up from combinations of the base units. By way of example, 1 Hz = $1 \times s^{-1}$ or 1 (cycle) per second and 1 N = kg × m × s^{-2} or 1 kilogram × meter per second per second. The derivation of other units will be given as and when they are encountered in the text.

THE INSPECTION ENVIRONMENT

At the outset, it must be understood that welding inspection is concerned only with ‘measurable’ quantities. Qualitative terms such as ‘good’ or ‘a smooth surface’ are not measurable. Welding inspection variables must be specified in specific terms, as measurable quantities.

Of the many variables associated with Visual Inspection (VT), the condition of the inspection environment plays a major role. In practical terms, the amount of light on the area being examined is very important.

Visible light is a member of the electromagnetic spectrum which is comprised of many different types of light energy. Visible light is shown in Table 4.2.4 to have a very high frequency and a wavelength range of 375 to 750 nm.

Figure 4.2.2 shows a representation of light energy as a waveform. The term Lambda, l , represents the wavelength of the light. Frequency refers to the number of wavelengths per second.

Visible light is also referred to as ‘white light’, and is comprised of a combination of violet, indigo, blue, green, yellow, orange, and red components.

The amount of light and the angle at which it strikes the test area, are vitally important. Too much or too little light will interfere with the inspector’s ability to observe all the features that could potentially affect the result. Excessive light (glare) makes the use of some instruments very difficult. Thus, control of the light source is essential.

To control lighting, it must be measured in quantifiable terms with a light meter or radiometer. The basic unit of illuminace is the Lux (Lx) (1Lx = 10.76 foot-candles).

Figure 4.2.3, shows one type of light meter, beneath an ultraviolet light. At the top of the light meter is a small white component; this is a ‘sensor’. The sensor shown is for visible light. It can be replaced with a sensor that will measure ultraviolet light illuminance. The ultraviolet spectrum is from about 0.1 to almost 400 nm. For UV inspection purposes, the long wave portion, known as the ‘A’ band, is used, typically at 365 nm; hence the term ‘UV-A’. As with other instruments, and particularly meters, calibration is of vital importance. Only instruments that have current calibration stamps or stickers attached should be used. When a light meter is unavailable, an 80 w fluorescent light at 1 meter, or a 100 w tungsten light at 200 mm gives approximately 500 lx. However, this alternative should only be used as a last resort.

Most welding inspection is carried out on areas at between 300 and 400 mm from the eye. Hence, near vision acuity is particularly important. So too, is color perception. AWS D1.1 and QC-1 require all inspection personnel (welding and NDE) to have a minimum visual acuity level, corrected or uncorrected. Further, color perception tests for red-green and blue-yellow recognition are often mandatory for welding inspectors. These, along with other prescribed tests, are to be carried out by eye care professionals.

FACTORS AFFECTING VISUAL PERCEPTION

There are many factors that affect visual perception of an object. These include influences from such widely disparate sources as past experience and present mental state. Assumptions based on illusions are well known. Most people are deceived by the optical illusion shown in Figure 4.2.4. The shafts of the arrows, while in fact of the same length, often appear at first glance to be of different lengths. Care is necessary to ensure that this type of illusion does not arise during an inspection. Fatigue and an inspector’s

general health can be very significant in inspection performance. The image of the object can only be described from the optical experience, not measured in precise terms. Fatigue and ill health usually create impediments to the effective description of what has been observed.

The angle of viewing an object has a significant effect of how that object is perceived. Changing the viewing angle is helpful since perception from one angle is different to that from another. The suggested range of viewing angles is shown in Fig. 4.2.5.

WELDING INSPECTION

Generally, the visual inspection of welding is carried out at four distinct stages, namely:

A. At or near order acceptance,
B. Prior to the commencement of welding,
C. During the operation of welding,
D. Following the completion of welding.

Details of the minimum checks to be carried out at the respective stages are set out in Table 4.2.5, at the end of this section. During each stage, the welding inspector will be looking for different aspects.

Verifying at the time of order acceptance that the requested order and the final bid correspond is the single most important task. This and other data such as applicable codes and specifications are extracted from the contract documents. Company records are the source of WPS and WPQ documentation.

Prewelding inspection is mainly concerned with dimensions and fit-up of joints. In-process inspections are usually directed to weld bead placement and gross discontinuities such as surface breaking slag and porosity. In both instances, inspections are often limited to specific areas. Post-welding inspection is a general overview, particularly of the areas of welding, and should be carried out from several angles.

IN-PROCESS WELDING INSPECTIONS

In addition to the normal requirement of in-process inspection, there is an additional activity that may be required when welding is to take place from both sides of a joint. The root of the first pass tends to be irregular, metal will be oxidized, and there is a high likelihood of porosity or other discontinuities being present. Root treatment, in the form of ‘back gouging’ is carried out to ensure that all metal of doubtful soundness has been removed before applying the first pass from the back side of the joint.

The term “back gouging” derives from the original method employed to “remove the back of a weld to reveal sound metal over the length of the joint”, which are the words of the original definition. This has been replaced by the current definition of ‘back gouging’, taken verbatim from AWS A3.0 - Standard Welding Terms and Definitions, which reads as follows: “The removal of weld metal and base metal from the weld root side of a welded joint to facilitate complete fusion and complete joint penetration upon subsequent welding from that side.”

Before the advent of elastic grinding wheels and angle grinders, chipping was the customary method used to ‘back gouge’. However, for some work, and when the shop was suitably equipped, air assisted carbon arc gouging was used after its introduction in the late 1950s. For many applications this is still the method of choice. When correctly

executed, the groove may be clean and suitably shaped for welding without further dressing.

However, backgouging, now designated as CAC-A, is noisy, dirty and represents a potential fire hazard. Therefore, the tendency is to use grinding for ‘back gouging’. While generally convenient and simple to apply, back grinding of welds is not without the potential risk of problems. The groove shape tends to be in the form of a parallel-sided U, which is not suited to receiving the back weld. There is a tendency for grinding to smear metal over and conceal smaller discontinuities. Even with a dye penetrant check, such areas may not be revealed. It is sometime recommended that when back grinding, a gas flame should be passed over the resulting seam on steel to cause any burred over metal to glow. This may also be done to areas for repair.

POST WELDING VISUAL INSPECTION

All accessible surfaces of the weld, together with the heat affected zone and the base metal for at least 50 mm on either side of the weld are to be considered as the ‘weld area’. In making an inspection of this area, it should be carried out in a methodical manner. It should not be a quick glance over the surface but rather a structured survey of the area with observations from at least 90° and 45° on either side of the normal.

The suggested scanning pattern is illustrated in Figure 4.2.6. Moving across the width of the weld area at 45° combines longitudinal and transverse capabilities for identification. This ‘pattern’ is also used in a PT or MT examination.

The visual inspection should be carried out in small ‘blocks’, no more than 400 mm long. The eye has no memory and thus cannot retain information from one area to compare with that seen in another. Comparison is wholly a mental process where what has been seen previously is stored in a descriptive rather than a pictorial manner.

Broad indicators are uniformity of bead width, its spacing, and regularity. The shape of weld ripples and the amount and type of spatter present should be identified. Also, the general weld profile and the angle made with the base metal should be examined. The manner of weld commencement and termination, and the appearance at stop-starts all give a general guide to likely weld quality. Evidence of arc strikes in the weld area or elsewhere on the work piece should be noted.

When stop-starts are higher than the weld bead, they should be investigated by lightly grinding the protruding metal. The presence of porosity indicates welding technique shortcomings. Depressed weld terminations should be more closely examined for the possible presence of crater cracks.

Where the weld bead is wide, the inspector must check for possible center line cracking; likewise for single-pass fillet welds, particularly those on the second side of a T-joint. As the restraint increases, the risk of discontinuities increases. Where possible, ensure that such welds are made in a controlled sequence.

Fillet welds exhibiting bulging towards the ‘horizontal’ member of the joint indicates the possibility of overlap. The ‘vertical’ member may be undercut in this situation. When checking for undercut, use the appropriate gage. Depending on the requirements of the applicable code, the maximum undercut will typically be 0.25 mm (0.010 in.), 0.8 mm, or 1.6 mm. A combination gauge is a useful inspection accessory (see Figure 4.2.7).

Each welding process has characteristic features the inspector should keep in mind when making a visual examination. For example, the possibility exists for

incomplete fusion with short-circuiting gas metal arc welding (GMAW-S). Evidence of this will often appear on the final weld bead.

Marking the limits of the areas that have been inspected and found to conform to the specified requirements is a recommended practice. Too often, a blanket report is considered adequate. Effective quality management systems usually spell out the way in which non-conforming product is to be identified. Segregation is often required to ensure it is correctly handled and not incorporated into conforming product.

What is sometimes omitted is how inspected and conforming product is to be identified. The SCWI should make a special point of monitoring the positive identification of conforming product.

VISUAL INSPECTION LIGHTING REQUIREMENTS

The importance of suitable illumination of all areas to be inspected has already been emphasized. However, achieving these levels of illuminance in some locations may be difficult. Where portable lighting cannot be used, a reasonably high power flashlight is a suitable alternative. For in-service inspections, a flashlight is an absolute necessity. For production work, it is frequently helpful and for internal work and in corners, a necessity.

A flashlight is a primary aid for supplying a portable light for welds in awkward places. It may also be used to augment general lighting to assist in the detection and/or identification of specific discontinuities. Where access may belimited and it is not possible to view the weld area from several angles, moving the flashlight to a corresponding number of oblique positions is a good substitute. The shadows cast by particular features in the weld area can alert welding inspectors to potential problems and are most helpful with undercut.

SAFETY CONSIDERATIONS

It is recognized that at some level, there is just too much light. The general term used to cover this is ‘glare’. It is also logical to suppose that at some level of glare, damage to the eyes and even body cells, will result.

For example, inspectors are well aware of the bright light produced by the welding arc. The light produced form the welding arc not only produces intense light in the visible range but also creates infrared and ultraviolet radiation which can be quite damaging to the unprotected eye.

Infrared radiation has the effect of heating body cells. This is known as ‘hyper-thermic’ and the absorbed heat can damage and even kill cells in the exposed areas. However, the intense heating is very painful and the normal reaction is to move away from it, hopefully before any lasting damage has been done.

At the other end of the visible spectrum is the ultraviolet (UV) region. The cornea and the lens of the eye are greatly affected by UV light. ‘Arc eyes’, known medically as ‘keratoconjunctivitis,’ results from exposure to the UV light of the electric arc.

Ultraviolet light, at a wavelength of 365 nm is used in magnetic particle and penetrant inspection, particularly when searching for very fine cracks. Certain substances fluoresce under the influence of UV light. The greenish yellow emission has a wavelength of approximately 550 nm and thus is in the highest visibility spectral region.

A possible problem when the eyes are exposed to longer wavelength UV radiation is that the lens of the eye may fluoresce. This promotes eye strain and headache. The resulting fatigue can interfere with an inspector’s work, as discussed above.

A potential effect of excessive, long term exposure to UV radiation is the development of cataracts. UV radiation, which is used in the range 285 to 340 nm for sun tanning, also promotes premature aging of the skin. The risk of developing certain types of skin cancer is significantly increased. Some people are ‘photosensitive,’ meaning they are sensitive to sunlight. This is generally a sensitivity to UV light.

Although the welding inspector may potentially be exposed to many sources of UV radiation, observance of a few simple rules can avoid the development of problems. Such sources include, but are not limited to: electric arcs, sodium and mercury vapor lamps, halogen lamps and fluorescent tubes.

However, UV light is attenuated by many transparent materials, such as glass and many common plastics. The use of industrial (safety) glasses, or even normal spectacles affords good protection. Minimizing the exposed portions of one’s body by the use of gloves, transparent face shields and industrial dress is usually all that is necessary.

MAGNIFIERS

Magnifiers of various types are another valuable aid in welding inspection (see Figures 4.2.8 and 4.2.16). A suitable magnifier is only partially determined by its magnification. The quality of the resulting image is most important. A magnification of 6X - 10X is usually adequate. The higher the magnification a lens, the less the field of view, (see Figure 4.2.9). The requirement for illumination becomes greater as the magnification increases.

Optical quality lens should be used. A measuring ‘reticule’ (see Figure 4.2.18) is a very worthwhile adjunct to the basis magnifier. Built in illumination overcomes the problem of light on the area of interest. Several types are available, each having particular advantages and limitations. Of importance are the number of lens elements, working distance, the field of view, eye relief, depth of field and magnification.

Single lens, 6X magnifiers are often satisfactory. For greater magnification, multi-element lenses provide the best resolution and correction of aberrations. For welding inspection, working distances are generally small; contact with small welds in T-joints limits the lens diameter. The field of view decreases with magnification; if a 5X lens of a given type offers a 40 mm field of view, the corresponding 10X lens will have a field of view of approximately 12.5 mm.

‘Eye relief’ is the range of distance from the eye to the magnifier that provides a full field of view. ‘Depth of field’ is distance between nearest and furthest points at which a magnifier in a fixed position remains in focus. Magnification affects the distance from the eye to the area being viewed. The nearest the eye will normally be to the job is 300 mm. If the eye is moved closer, magnification increases but the focus will deteriorate to some unacceptable limit.

BORESCOPES

A borescope is the engineering equivalent of the medical ‘endoscope’, used for internal examinations of patients. The borescope is likewise used for examining the interior of engineering structures, machines, equipment, pipe systems and a wide range of weldments. As with its medical counterpart, both rigid and flexible instruments are used.

As with magnifiers, borescopes are optical instruments. Figure 4.2.10 shows the field of view of a rigid borescope. A cable attached to the eye piece conveys power to the illuminating lamp within the instrument. The lens system inverts the image so that it is

‘upright’. The observer’s view is thus in the correct orientation on both axes. Image magnification is dependent on the distance from the object to the lens.

For instance, a well known borescope, with a 10 mm diameter tube, almost 300 mm long, has a field of view of 75°, a fixed focus of from 6 mm to infinity, and magnifies at from 6X at 6 mm to 1X at 30 mm lens-to-object distance.

As an optical instrument, the lens systems of borescopes are ‘matched’ units. As shown in Figure 4.2.11, the instrument has an ‘ocular’ lens through which the user looks, possibly a focusing adjustment and terminates in a second lens, known as the ‘objective’.

A related instrument is the “Fiberscope”. The fiberscope uses many pairs of ‘bundles’ of small glass fibers. One bundle in a pair conveys light to the work area while its second bundle of fibers carries an ‘image’ of the object of interest back to the inspector. In most cases, fiberscopes can be bent to quite small radii, which facilitates visually inspecting otherwise inaccessible weld roots and around tight corners. The general mechanics of a fiberscope are shown in Figure 4.2.11.

Each glass or plastic tubular fiber is quite small, typically 0.25 mm or less. Each fiber has a coating of lower refractive index, which causes light in the tubular fibers to be reflected internally from the tube walls. This is shown in Figure 4.2.12. A ‘bundle’ of fibers may consist of hundreds or even thousands of fibers, each capable of conveying light considerable distances.

The light being introduced into a glass fiber must be ‘cold; otherwise, there is a risk of heating the individual delicate glass fibers. For this purpose, ‘cold light generators’ are used.

Flexible fiberscopes may be from as small as 2 to 3 mm OD but are more usually of the order of 10 to 12 mm. Lengths can reach 5 meters or more. As with most optical instruments, the cost of fiberscopes is not inexpensive, and start in the low four-figure region. It is relatively simple to enhance fiberscopes by the use of miniature electronic cameras connected to video screens and/or recorders.

Similarly, the recording of inspection data may be simplified by the electronic retention of selected or multiple views of a particular area of interest. For instance, in mechanized welding, observation of the root pass both as the basis of parameter control and of the physical appearance of one or more areas of interest is possible.

Fiberscope units are typically single-arm stand-alone systems used on an as-required basis or as a fixed installation. However, bifurcated or split units are also available. Such equipment facilitates work area observation in applications such as multiple arm robot welding.

As with all mechanical and electrical equipment, there are certain precautions to be observed in use and maintenance. With any optical instrument, clean the lenses only with a soft cloth. Never try to take optical instruments apart. If there appear to be internal problems such as foreign matter on a lens, send it to the supplier or authorized repair station. Fiber optical equipment should never be bent through more than 360°, nor too sharply around bends or curves. It should not be left in strong sunlight or used in environments where the temperature may exceed 100°C, or lower temperatures than specified by the manufacturer.

An alternative to the flexible borescope are video probe units. Equipment is available having a cable length up to 15 meters or more, with a diameter of 12 mm or

less. A miniaturized video unit, black and white or color, feeds a signal which can be viewed on a monitor or videotaped.

ETCHING

There are two related areas where ‘etching’ of a metal surface may be required. Most codes require some specific action in the correction of arc strikes. Further, in the repair of cracks, codes typically require either NDE or etching to determine the extent of cracking, and during the preparation for repair, the complete removal of the crack.

Etching, as the name implies, uses etching reagents or ‘etchants’ which are typically strong acids or alkalis. In the handling of these substances, considerable care must be exercised to avoid injury. To a greater or lesser degree, all ‘consumables’ used in nondestructive testing represent a safety hazard. For each substance, it is strongly advised that the SCWI have the applicable product MSDS, the Material Safety Data Sheet, available.

Additionally, an OSHA requirement is that MSDSs are available for all such products. The SCWI has a direct responsibility to ensure that all nondestructive tests are carried out in a safe and non-hazardous manner. This is in addition to the implied responsibility to take all available steps to stop hazardous practices observed in the course of work.

Before the development of elastic grinding wheels, chipping was used for the removal of cracks. It was relatively easy to see from an examination of the chipped area where a crack terminated. Grinding has greatly facilitated many aspects of welding, but it does tend to burr metal over fine discontinuities and mask their presence. This smearing does not normally affect the magnetic particle method, but it does render penetrant testing of doubtful reliability. Some codes and standards require etching of this area to reveal any discontinuities.

Etching is normally used to reveal certain features of a macro- or microsection of a metal. It does this by selective removal of phases of the metal being examined. In VT, it can simply serve to remove smeared metal that may be concealing a crack-like discontinuity. The etchant required is dependent on the metal being examined. Acids are used for the ferrous metals and certain non-ferrous alloys. Alkalis are used for other non-ferrous metals, in particular, aluminum alloys. A 10% aqueous solution of sodium hydroxide at 50 to 80° C is commonly used. For plain carbon and low-alloy structural steel, 50 g of ferric chloride ($FeCl_3$ $6H_2O$) is dissolved in 25 ml of water. Then 75 ml of concentrated nitric acid (HNO_3) is added with continuous stirring. The solution is applied to the surface by medicine dropper and allowed to react for up to 5 minutes.

The etched area is then washed with water and dried by swabbing with alcohol. For stainless steels, an etchant can be made up by adding 30 ml of concentrated hydrochloric acid to a solution of 10 g of ferric chloride in 90 ml of water.

REPLICATION

‘Replication’ is a process for duplicating an area of a surface for preservation or further examination. It reproduces the topography of the surface, using a variety of media. To illustrate the principle, the cellulose acetate method will be reviewed. The basics are depicted in Figure 4.2.13.

View (a) shows a cross-section of the surface to be replicated. In (b), a softened section of acetate film is applied to the whole of the surface of interest. In (c), the film is curing in place and in (d), the replica is removed. This creates a single stage or ‘negative’

image of the surface. Positive or second stage images may also be prepared from the negatives.

TEMPERATURE MEASUREMENT

In operations where heating and cooling are essential and vital parts, the measurement of temperature is an important function. As individuals, we are sensitive to changes of temperature in a qualitative sense. Precision in the measurement of ambient temperature is rarely a critical factor; tolerances within a few degrees are usually acceptable.

The same general statement applies to temperature control in welding. However, if these data are unspecified, it is essential the SCWI has sufficient knowledge of temperatures to fix appropriate tolerances. As a foundation, the basis of temperature measurement will be reviewed and examples of several methods will be considered.

Originally, temperature was measured as a variation from some arbitrary ‘zero’. Later, for repeatability, the concept of degrees was introduced, which required that a second point be established. Water was chosen as the reference medium, and its freezing and boiling points selected as the fixed limits. In the Celsius scale, or centigrade scale, the difference was divided into 100 equal parts or ‘degrees’. In the Fahrenheit scale, the same interval is divided into 1800.

When it became apparent that heat as such was a form of energy, it was postulated that at some point, there could be zero energy and consequently, no heat. Using this proposition, Joule and Kelvin established the absolute zero as being -273.16°C. This is the basis of the Kelvin scale of temperature. Graduations in the Kelvin scale are those used in the Celsius scale. To convert temperatures to degrees Kelvin (also known as ‘degrees absolute’) 273.16 is added to the Celsius temperature. In general, while °C are more commonly used in scientific work, certain engineering formulas utilize °K. For instance, the gas laws relating temperature to pressure and volume utilize °K.

Several methods are used to establish the temperature of a body. Some, but not all of these techniques, have some relevance in welding. Older methods are still used in scientific work and in electronic instruments. These are typically based on:

1. The change of gas pressure at constant volume or
2. The change of electrical resistivity.

As already noted, extreme accuracy is not a usual requirement for welding. Temperature measurement techniques of interest include:

1. The expansion of a solid, liquid or gas.
2. The Seebeck thermoelectric effect.
3. The color of very hot bodies.
4. The radiation from a heated body.
5. The melting of a specific substance.
6. Temperature sensitive stickers.
7. Liquid crystal indicators.

The best known temperature measuring device is probably the ‘mercury in a glass tube’ thermometer. Such instruments are typically a glass tube, partially filled with mercury. The effective temperature is usually within the range from about -20°C to 120°C. The internal pressure constraint of such thermometers usually necessitate shaking down the mercury column to return it to zero . A variation is the ‘dyed alcohol’ thermometer. A column of dyed liquid, either pure alcohol or other suitable substance, is

used in a transparent glass or plastic tube. This enables lower temperatures to be measured. This type of instrument may be used in sub-zero impact testing. Typically, specimens to be tested are placed in a beaker containing alcohol or ethyl glycol. Pellets of solid carbon dioxide are added to attain the specified test temperature. The selected thermometer is immersed in the liquid and monitored as required.

The greatest drawback of the glass thermometer is its delicacy, particularly at low temperatures. Electronic counterparts exist where a ‘stem’ of a tube, of fixed volume, contains a gas. Variations in pressure, caused by a temperature change, are detected by a suitable circuit and a liquid crystal readout displays the temperature. The useable temperature range is greater than that of the liquid-in-glass thermometers.

The Seebeck effect, observed first by a scientist of that name, is used extensively in temperature measuring devices. The basis is pairs of different metals in a circuit securely joined at a point. This is known as a ‘thermocouple’. When the thermocouple is exposed to a temperature different from that at another point in the circuit, a voltage will be generated. Kelvin later observed that even with a single metal conductor, a similar but greatly attenuated potential is generated.

Each pair of metals has a limiting temperature. In the case of a thermocouple of copper and iron, the limit is 275°C. To cover a range of temperature from sub-zero upwards, various couples have been developed. At the low end, iron and copper are used. For higher temperature, alloys of nickel and iron or nickel and aluminum are used. Platinum and alloys of platinum with iridium, chromium, or rhodium are used in foundry work and other situations where high temperatures are encountered.

For direct welding inspection, a digital pyrometer shown in Figure 4.2.14 is commonly used. The ‘couple’ is at the tip of the insulated probe, shown on the right. Typically, the tip of the probe must be in contact with the surface for a few seconds to allow it to reach the temperature of the item.

Needless to say, calibration of this type of instrument is very important. The frequency of calibration will be dictated by the Quality Management System, or by apparent irregularities in service.

The instrument shown has digital readout, with typical accuracy to within ±1 to 3°C over the range of measurable temperatures; this is usually adequate for welding. Other types of probes are available. For temperatures less than l,000°C, a copper/chromium tip of 2.5 mm diameter provides virtually instantaneous readings. The tip, itself brazed to the couple junction, is hard and durable yet has good conductivity.

Probe lengths in the range 40 to 400 mm are common but longer probes are available for specific tasks. For foundry work, probes suitable for immersion in molten metal are available. Needless to say, temperature readings may be recorded by the use of appropriate equipment.

For postweld heat treatment, multiple pen recording charts are commonly employed. The key factor in this task is the placement of the thermocouples. These are usually mechanically attached or brazed to the work piece in selected locations. By and large, thermocouples should be attached to the lower extremities as well as the lower midpoint. However, to ensure there is not significant temperature gradient, attention must also be paid to the outer upper parts also, where the temperature is likely to be higher.

Code-specified maximums with respect to heating and cooling rates are usually given. These data may also be extrapolated to ensure a satisfactory temperature gradient

between one part of the job and another is achieved. Keep in mind that while thermocouples fixed to a furnace structure may be convenient, it is the work piece temperature that counts. For alloy steel work in particular, be conscious of the cooling rate associated with attaching the thermocouple pairs. For higher temperature work, such as normalizing, a different approach may be taken. Although thermocouples can be used, often an optical pyrometer is employed as temperatures exceed 1000°C. The basic form of this instrument is shown in Figure 4.2.15. Equipment of this type looks like a short telescope. The hot body is viewed through the eye piece and adjustments made to determine the object's temperature.

THERMOGRAPHY

While it may not be visually apparent, all heated bodies emit radiation. Another method of temperature measurement, known as 'thermography', measures the radiation emitted by bodies above 'absolute' zero. While the theory dealing with this subject is well known and dates back to the 19th century, it is only relatively recently that use has been made thereof. This has been facilitated by the development of electronic circuitry able to perform the functions needed to implement the technology.

Visually, we cannot perceive a change in a steel surface until the temperature reaches 400 to 500°C. However, even at sub-zero temperatures, the steel will be emitting radiation. While this radiation will tend to be over a broad frequency band, it has been found expedient to measure the infrared portion of the emitted spectrum. The technique of thermography used is thus known as "thermal infrared testing", or TIR.

Certain constraints are imposed by differences in emisivity exhibited by a range of materials. Based on practical work, a range of 'emission factors' has been developed. As a temperature-specific-function, it is readily evident why microprocessors are required to implement the technology at a practical level. A plain carbon steel with a polished surface at 100°C, has an emission factor of 0.07. The same specimen, if oxidized at its normalizing temperature, will have an emission factor of 0.70 at 100°C. In using TIR, all appropriate emission factors must be known and programmed into the instrument.

As can be seen from the diagram in Figure 4.2.15, the basic part of the instrument is centered around a short telescope. This enables the location of testing to be very precise. For instance, loose electrical connections in a welding (electrical) circuit can readily heat up locally. This in turn increases local resistance, which further exacerbates heating. In a short period of time, the welding parameters will have to be changed to maintain WPS values. This example is cited to illustrate one potential use of the TIR method.

Another use for TIR is the detection of 'hot' or 'cold' areas in operating equipment. TIR will detect areas having temperatures different from surrounding areas.

While TIR equipment can be a very important adjunct to welding, industrial instruments of this type are rarely, if ever, purchased solely for this purpose. The cost tends to be high - > $10,000 for most models, but some smaller units, some with 'laser' targeting, cost about $1,000. For low temperature heat treatments, typically preheating and/or tempering, TIR instruments can give accurate temperature readings in specific parts of a job. This ability is used to avoid the development of sharp temperature gradients in a fabrication.

TEMPERATURE SENSITIVE MATERIALS

Temperature can also be measured using “temperature crayons”, which typically cover the temperature range from 125 to 350°C. When stroked across the area of interest in ascending order, the first crayon that melts shows that the area has reached or exceeds the indicated temperature.

INSPECTION ROLE IN MECHANICAL TESTING

In a variety of circumstances, including procedure qualification, welding inspectors may have to witness mechanical testing. The basic role is to witness the testing and to record results. Coincident with this is the need to ensure conformance of the specimens to be tested with the applicable specifications. For example, AWS D1.1 requires certain tolerances to be maintained with test specimens.

Specifications for specimens to be mechanically tested must have dimensions within certain tolerances. Other requirements, such as surface finish, can affect tensile test and impact test results. For such work, familiarity with surface finish or roughness comparators, is essential. For each finishing method, a set of ‘standards’ is used, small metal blocks of known surface roughness. A replica of a standard set is shown in Figure 4.2.17. The technique to use is ‘tactile comparison’. A clean fingernail is lightly drawn over the specimen surface and then over the surface of the required standard for comparison.

Charpy -V Notch SPECIMEN

With Charpy-V notch specimens, the surface finish, notch, and particularly the radius at its root, are critical. Should these not be within the applicable specification range, the results are of doubtful value. The dimensions are quite small; the notch depth of 2 mm terminates in a radius of 0.25 mm. Details are found in ASTM E 23.

The most satisfactory method of measurement for these features of the notch are by use of an ‘Optical Projector’. This equipment is a specialized type of optical instrument; and the magnified detail may be measured by the use of appropriate ‘reticule,’ Figure 4.2.18. Figure 4.2.16 shows a portable magnifier which is often used for such measurements. The reticule is placed in the end of it.

Reticules are available in many patterns, collectively suitable for almost any fine measuring task. At the lower end of the scale, the illuminated Coddington (magnifier) shown in Figure 4.2.19, uses 20 mm removable reticules. Instruments of this type use much larger reticules, which enhances accuracy of measurement.

Another important factor in impact testing is specimen temperature. Cooling fluid immersion, agitated, up to 5 minutes is needed to ensure a uniform temperature of test specimens. Most laboratories equipped to carry out impact testing will have calibrated thermometers on hand so specimen temperature may be verified.

With bend test specimens, a corner radius of up to 3.2 mm (1/8 in.), is permitted. This largely avoids the problem of corner cracking, which can confuse conformance determination. A suitable radius gauge is suggested as part of the inspector’s tool kit if witnessing bend tests is other than an infrequent task.

Measuring weld size and attributes

Apart from the usual measuring instruments, welding inspectors at all levels are required to be familiar with the use of the more specialized welding instruments and gauges. Several options are available.

Certain ‘universal’ instruments may be used for a wide range of determinations. Typical is the ‘bridge cam’ gauge, illustrated in Figure 4.2.20. With this instrument, it is

possible to measure fillet weld throat and leg length, weld preparation (bevel) angle, undercut depth, excessive reinforcement and misalignment.

For measuring the size of fillet welds, another alternative is to use a separate set of gauges. This enables both leg length (for convex profile welds) and throat size (for concave welds) to be determined on a ‘go-no go’ basis. A set of seven gauges, able to measure 11 fillet welds sizes in the range 1/8” to 1”, of either convex or concave profile, is shown in Figure 4.2.21.

Important considerations in measuring fillet welds with the above type of gauge is that of determining weld profile. Without knowing the weld profile, the correct gauge cannot be selected. For convex profile fillet welds, both legs are measured. For concave profile welds, it is the throat measurement that is taken. Fixed gauges automatically convert this to the corresponding weld size.

A different type of fillet weld gauge is illustrated in Figure 4.2.22. This gauge is able to measure both legs of a fillet weld at the same time. The throat dimension may also be measured, and a direct reading obtained. For instance, European fillet weld sizes are specified as throat depth. This type of gauge is thus able to measure fillets in those terms.

For pipe fabrication, it is of particular importance that adjacent pipes are in good alignment. Frequently, because of diametrical, out-of-round and wall thickness tolerances, a condition known as misalignment, or ‘hi-lo’ develops. Codes generally permit some hi-lo and to measure this, a suitable gauge is invaluable (see Figure 3.1.5).

Such gauges comprise a two part assembly where one member is free to slide with respect to the other. For external measurement of hi-lo, the respective legs of the instrument are placed astride the weld prep. One leg rests on each pipe and any difference is noted for compliance to the code. In a similar manner, weld bead height may be determined.

To measure the internal hi-lo, suitably shaped jaws are entered into the weld preparation and rotated thought 900. The jaws are then drawn up against the inside of the pipes and the respective dimensions compared. When using sockets for making fillet welds, the gauge also enables accurate limiting lines to be inscribed on pipe ends.

A problem with most gauges and measuring instruments used in connection with welding is the errors that may develop as a result of limited access. The fillet weld gauges typically require about 100 mm for seating. Where this is not available, speciality gauges may be useful. One of a combination set of three such gauges is shown in Figure 4.2.23.

The measurement of weld sizes of skewed T-joints has always presented a problem. Typically, welds on both the acute and obtuse sides of such joints must be verified. A gauge to cover such measurements is shown in Figure 4.2.24. The gauge itself provides input for a calculator-type slide rule, using the appropriate geometrical ratio. For the instrument depicted, the supplier also furnishes a ‘slide rule’.

The slide rule type mentioned above may also be used to determine required weld size. By its use, after calculating the required effective weld throat, the designer or detailer is able to calculate the actual weld sizes that will produce a weld having the effective throat required by the design. Welding speciality suppliers offer a wide range of other gauges, instruments and tools to facilitate welding inspection.

INSPECTION OF STAINLESS STEEL WELDS

The welding characteristics of stainless steels, from the inspector's perspective, are dealt with in the metallurgy section of this program. It was noted in section 3.2 that when welding austenitic stainless steels, it is desirable to have some ferrite in the weld. A presence of ferrite in the otherwise austenitic weld metal reduces the risk of center line fissuring. The risk may become acute when welding the fully austenitic grades, such as Type 310.

A two stage approach is used to deal with this potential problem:

First, during welding procedure development, an estimate of the likely ferrite in the weld is made. For this purpose, a DeLong diagram is used. The percentage dilution is estimated, based on weld type (groove or fillet, butt or T-joint), and joint member thickness (see Figure 4.2.25).

From the respective analyses of base metal and filler metal, an estimate of the amount of ferrite likely to be present in the weld is made. This may be found as a percentage of ferrite or as the 'ferrite number' (FN). It is usual for purchase specifications to limit the amount of ferrite allowed to preserve the chemical or thermal passivity for which the metal was selected.

The second step is to verify the actual ferrite content of the weld. For this purpose, there are two possible methods. The (delta) ferrite content may be determined by the use of a 'ferrite meter' (FN). It is a modified eddy current machine and thus gives a reading for a very small area only.

A second approach, recommended by AWS, uses a 'ferrite balance'. Such instruments give the ferrite number for the test area. Instruments can assume a number of forms but the common purpose is to compare the magnetic response from the test area to standards of known ferrite content.

It is customary practice when ferrite content is specified to do so either as a limit or as a range. For instance, a purchaser may specify, "not to exceed 4FN". In another instance, a range may be specified as "delta ferrite within the range 4FN to 8FN". Apart from it's potential effect on corrosion, ferrite may be limited as a precaution against the development of 'sigma phase'. Sigma phase has the ability to embrittle stainless steel welds, particularly in low temperature service.

Yet another consideration with stainless steel is the passivity of the surface in the weld area following welding. It is customary to apply a 'pickling paste' or similar material to welds in austentitic stainless steels; this overcomes discoloration following welding. Pickling compounds usually contain oxidizing media and deoxidizers which strip all the existing iron oxide film.

While the chromium oxide film is theoretically re-formed instantly in the weld area, the surface may not develop the full thickness of oxide film needed to restore the resistance to corrosion of unwelded metal. A process, known as 'passivation', is used to optimize corrosion resistance and assure its uniformity over welded and unwelded surfaces. Passivation solutions are used to promote the formation of a chromium oxide film of uniform density and thickness.

When working with fillet welds or in repair situations, the back of the welded area should also be pickled and passivated. Passivity can be checked by a 'passivation meter', especially designed for this purpose. When working with stainless steel, possession of such an instrument is most desirable. From the supplier's point of view, it mitigates against the possibility of local corrosion, particularly that possibly associated with

welding. From a purchaser perspective, it provides a measure of added assurance with respect to the quality of the product.

CYCLICALLY LOADED STRUCTURES

Cyclically loaded structures impose special requirements on designers, fabricators and particularly, inspection personnel. Among the many applicable considerations, joint design and weld profile are of particular importance. If not already shown on detail drawings, the basic rules for joint design for cyclic loading include the following:

1. All butt joints to be made with full joint penetration groove welds. Weld face and root reinforcement to be finished flush and ground to a smooth finish in the direction parallel to the loading axis;
2. All T-joints to be full penetration groove welds. A superimposed concave profile fillet is to have 900 quadrant radius of not less than the thickness of the thinner joint member. The weld profile is to be ground to a smooth finish. The grinding marks to be 900 to the weld axis.
3. All welds are to be examined using RT or UT, with or without other NDE.

The purpose of these requirements is to ensure minimization of stress concentration in the weld area. In the case of steel structures, this is the area at risk. Due to the mechanical work experienced by weld metal during cooling, it tends to be somewhat harder than the surrounding base metal. This provides an unavoidable notch-like effect.

VISUAL INSPECTION OF WELDS

To this point, consideration has been given to the various aspects governing the mechanics of visual inspection. These principles are to be implemented in connection with the visual inspection of welds and welding. Table 4.2.5, sets out the suggested steps aimed at assuring
the integrity of welded fabrications. Each of these phases are important to ensure that the entire welding inspection function is performed for each product.

Summary

The role of the SCWI can encompass oversight and supervision of every facet of a job or contract. Visual Inspection, in the fullest sense of the term, is the key element in establishing weld and weldment quality.

By taking a planned series of preemptive steps, the suitability for intended service of welded products can be assured with a high level of confidence.

TABLE 4.2.5

WELDING INSPECTION PROGRAM

Phase A - Initial Review

1. Review Purchase Order, Codes, Drawings
2. Develop all necessary Inspection Plans
3. Check welding procedures, welder status
4. Review inspection documentation system
5. Verify non-conforming product ID system
6. Create job corrective action program

Phase B - Prewelding Checks

1. Check suitability, condition of welding equipment

2. Check conformance of base metal, filler metal
3. Check positioning of members and of joints
4. Check joint preparation, fit-up, cleanliness
5. Check adequacy of alignment maintenance
6. Check preheat (or initial) temperature

Phase C - In-Process Inspections

1. Check compliance with WPS provisions
2. Check quality, placement of key weld passes
3. Check weld bead sequencing and placement
4. Check interpass temperature and cleaning
5. Check adequacy of back gouging
6. Monitor any specified in-process NDE

Phase D - Post Welding Activities

1. Check finished weld appearance, soundness
2. Check weld sizes and dimensions
3. Check dimensional accuracy of weldment
4. Carry out or monitor/evaluate specified NDE
5. Monitor any PWHT or other post-weld work
6. Finalize & collate Inspection documentation

PENETRANT TESTING

Penetrant testing (PT) has been used over the centuries to establish casting quality; casting of metal is the oldest fabrication process. In the modern industrial era, penetrant testing is used to detect cracks and other surface-breaking discontinuities. The development of successful steam locomotion in the 18th and 19th centuries hinged in part on the use of penetrant testing. The penetrant itself was water, later a thin oil. Lime or chalk were used to provide an indication of likely problem areas.

Although there are many variations of the penetrant method, the basic principle is that otherwise invisible surface-breaking discontinuities are rendered detectable. After ensuring the surface to be examined is 'clean', a penetrant liquid is applied and allowed to remain in contact for a specified time. Penetrant remaining on the surface is then removed and a 'developer' applied. This acts to draw out any penetrant that has entered into cracks, fissures or other interruptions to the surface, thereby revealing their presence. Figure 4.3.1 shows a crack detected in this way.

Over time, process improvements have been made. ASTM E165, Standard Practice for Liquid Penetrant Inspection Methods provides the present standard methods of PT. Today we have two principal types of penetrant, namely:

- color contrast
- fluorescent

Within each type, options in terms of removal systems are available. These are:

- water washable
- solvent removable
- post emulsifiable

From the many possible combinations, the one combining the desired attributes and having the least drawbacks is obviously the first choice. Fluorescent penetrants are considerably more sensitive than color contrast types. This accounts for their use for the inspection of machined components and aircraft parts, for instance.

There are two broad divisions with respect to penetrant application. Possibly the major field of use of penetrants is by immersion of components in a series of tanks wherein the several steps of the process are carried out. For smaller weldments, this may be appropriate, but the bulk of welded fabrications requires 'custom' application.

In the case of welding and welded structures, color contrast penetrants are almost universally used. The greater sensitivity (at least by a factor of 10) of the fluorescent types leads to many non-relevant indications being detected.

The surfaces in the vicinity of welds and the ripples of welds are often too rough and/or coarse for fluorescent methods to be effective. Needless to say, this limitation does not apply to welded parts that have been machined or those having much smoother surfaces .

The excess penetrant removal system choice depends on the job to be examined and the environment in which the work will be performed. For convenience, welded components that are small and compact, or where water could create a corrosion problem, are examined using solvent removal penetrant.

For larger structures, particularly where relatively high volumes of waste water can be handled, water washable penetrants are generally more cost effective. Desirably, water is applied in the form of a low pressure large droplet spray.

Irrespective of the procedure used, the basic principles, shown in Figure 4.3.2, are simple and generally easy to apply.

Dye penetrant examination is dependent upon capillary pressure of the penetrant to draw it into the discontinuity. The relationship between capillary pressure and crack width is as follows:

$$P = 2S \cos \theta / D$$

Where:

P	=	capillary pressure
D	=	crack width
S	=	surface tension of liquid
Q	=	contact angle
Cos	=	cosine (a trigonometric function)

The meniscus shape of a liquid determines the contact angle for the liquid. This is shown in Figure 4.3.3. From the formula $P = 2 S \cos \theta / D$, it is noted the ideal penetrant will be one with a high surface tension and high wetting ability. These are the optimum properties for a good penetrant. Notice also, the smaller the width of the discontinuity, the greater the capillary pressure acting to draw penetrant liquid into the discontinuity.

PENETRANT PROPERTIES

Good penetrants are required to have several other characteristics. Chemical inertness is possibly the most important. For work on austenitic stainless steels, the penetrant must be free of sulfur and halogen containing compounds. The ability to be readily removed, using the appropriate solvent and the ability to dissolve the required dye (fluorescent or red for color contrast) are basic requirements. This latter capability must extend over the range of temperatures likely to be encountered in use and in storage. The flash point must exceed 90°C and it must not be so volatile that it will evaporate too readily when applied in a thin coating.

The other characteristic of a penetrant is that of viscosity. Superficially this is important, but only in respect to the time taken to enter a discontinuity. Viscosity does not affect a liquid’s ability to enter small spaces, but high viscosity liquids do take appreciably longer. For dip or pressure spray application, the draining time will also be extended considerably.

Penetrants from reputable manufacturers normally possess the required properties for the general PT. When a special base metal is being handled, it is prudent to ensure there will be no chemical interaction. Penetrants for nickel and its alloys must be sulfur free, and as noted earlier, penetrants for the austenitic stainless steels must be chloride and halogen free.

Penetrants can be applied to all solid, non-porous materials. Although largely confined to metals, the method does find some use with certain plastics. It is only suitable for surface breaking discontinuities as penetrant testing has no subsurface capabilities whatsoever. Penetrants may be used in connection with leak testing but by definition, leaks must be open to both surfaces with a connecting path.

PENETRANT SELECTION

Selection of the variables of penetrant application will be based on the work to be examined. As already mentioned, color contrast penetrants are sufficiently sensitive for most welded fabrications. The basic choice thus comes down to the removal system. While for the smaller jobs, and even some larger fabrications, the aerosol applied liquids

are suitable, there are occasions when other considerations apply. Figure 4.3.4 shows a typical test set containing cleaner-solvent, penetrant and developer.

For more extensive work, penetrant can be applied by pressure spray. For work in the overhead position, penetrants in a thixotropic gel are invaluable. Such gels are thick but become mobile when stirred.

The penetrant removal system is dependent on the extent of testing and the work area. While less expensive in time and materials, water washable penetrants are not always practical to use.

Superficially, post emulsifiable penetrants would appear to have little place in the examination of welds. Extra material and additional steps are required. However, for shallow, open type discontinuities, such as certain types of undercut and some instances of overlap, post emulsifiable systems work very well (Figure 4.3.5). There are two types of post-emulsifiable systems: hydrophillic (detergent, water-soluble) and lipophillic (oil-soluble).

Should the emulsifier contact time exceed 2 minutes, the diffusion process as shown in Figure 4.3.5 D, will cause penetrant in the discontinuity to be 'dissolved' and thus washed out of the discontinuity during the rinsing operation. An alternate to the post emulsifiable system is the water washable penetrant (Figure 4.3.6) which contains a detergent which permits the excess to be removed directly by water washing. These have the advantage of eliminating volatile organic compound (VOC) fumes.

AFTER PENETRANT REMOVAL

An additional consideration when choosing penetrant type and removal system is that of the surface condition after removal. With solvent removable penetrants, this does not present a problem when proper application techniques are used. This involves dampening a lint-free cloth or paper with solvent and removing the excess penetrant by progressive wiping. The test area is ready for the next stage when the cloth surface shows only a faint pink tinge.

With fluorescent systems, penetrant removal must be carried out under an ultraviolet lamp (UV-A). A faint purple signifies satisfactory removal. The approximate wavelength of such lamps is 365 nm (10^{-9} m). The suffix A refers to the range of ultraviolet light between 315 and 400 nm. A diagram of a typical UV-A lamp is shown in Figure 4.3.7.

After water washing, the test area must be dried. This may involve a hot air recirculating oven for smaller components; for larger items, forced hot air from a blower is useful. As the last resort, clean, dry compressed air, not exceeding 2 bar, may be used. With fine nozzles, 1 bar maximum at 45° and at not less than 300 mm from the test area is required. (Note: 1 bar = 1 atmosphere = 14.7 psi)

DEVELOPMENT

In penetrant testing, 'development' refers to increasing the indication's visibility so they may be readily seen. A range of 'developers' are available for this purpose. The type of penetrant, namely fluorescent or color contrast, determines developer type. A secondary division is developer form. Developers may be 'wet', as a suspension in a suitable carrier liquid or 'dry' as a powder of appropriate fineness.

There are several necessary properties for developers for penetrant testing. These include the following:

- Be able to take up and absorb penetrant liquid in a blotter-type manner.

- Be finely divided so it may ‘float’ on penetrant entrapped in a discontinuity, but without clogging the fissure.
- Be readily wetted by absorbed penetrant, yet will limit transfer in the developer to avoid too much magnification.
- Developers must be easily applied to give a light, uniform coating, readily removed after test completion.
- It must be non-toxic and non-irritant to skin and eyes in particular.

Developers for color contrast systems must be of a contrasting color, and be able to block out interference from contours of job shape and irrelevant colors; these are the requirements for the choice of color. Developers for fluorescent systems, in particular, must not be fluorescent themselves. Rather, they are required only to localize the fluorescence of the indication.

The mechanism of developer action is based on a combination of capillarity, light scattering and solvent action. For a color contrast developer, its capillary attraction must overcome the opposing attraction of the discontinuity for the penetrant, already retained within. For fluorescent penetrants, light scattering is vital to ‘magnifying’ indications. As shown in Figure 4.3.8, the developer particles reflect both the UV-A light excitation and the fluorescent radiation.

Developers for fluorescent systems are typically supplied as either a dry powder or as a suspension in a solvent. New, dry developer used in fluorescent systems is hardly visible in normal light, and does not fluoresce brightly under UV-A light. Being hydroscopic, avoid
inhalation as it dries up nasal passages, causing discomfort. It is dispensed from a ‘puffer’, a flock spray gun or in a dusting cabinet.

Aqueous liquid developers are ‘water soluble’ (used for fluorescent systems) or ‘water suspendible’. While they may be sprayed on, the usual application is to dip (30 s max.) and drain. Development takes place during drying.

Non-aqueous (solvent-suspendible) developers are finely divided white powder in a carrier of trichloethane. Sulfur and halogen free developers use acetone or naphtha based carriers. These developers are sprayed from aerosol cans or spray guns

A light, uniform film of developer is applied to the test surface. Where penetrant has been retained, it is absorbed into the developer and becomes visible, and possibly magnified, as penetrant from the discontinuity is drawn up by the developer. This is shown in Figure 4.3.9.

For color contrast systems, optimum viewing conditions for determining type, size and location of discontinuities is to have a minimum of 500 lux at the test surface. This is equivalent to an 80 watt fluorescent tube at 1 meter or a 100 watt tungsten filament lamp at 200 mm.

For fluorescent penetrants, development is not always an absolute necessity. In many cases, some indication of discontinuities will be evident prior to development. Dry developers are dispensed from an insufflator (puffer) or applied in a dust storm cabinet. Developer greatly enhances visibility of an indication. This is shown graphically in Figure 4.3.10.

The background lighting conditions for viewing fluorescent penetrant indications should be less than 10 lux of white light. For fluorescent penetrant testing, the minimum

irradiance of the UV-A amp is to be 0.5mW/cm^2 at the test surface. In the next Section, it will be seen that for MT, the corresponding UV-A intensity value is 0.8mW/cm^2.

When using UV-A lamps, there are several important safety precautions to be observed. These include:

- Do not look directly at the UV-A lamp.
- Do not use the lamp without the correct filter.
- Do not operate the lamp with a chipped or cracked filter.
- Avoid contact with the lamp housing. It becomes hot in service.
- Keep cable to lamp away from all PT liquids.
- Periodically check ground to lamp housing.
- Photochromatic spectacles can be damaged by exposure to UV light.

The following operating instructions for UV-A lamps should also be implemented:

- Warm up the lamp for at least 5 minutes (15 minutes desirable) before inspecting with the lamp.
- If the lamp has been switched off, it will not relight until it has cooled to a certain temperature.
- Avoid repeated switching on and off, as this reduces lamp life.
- Angle the lamp with respect to the test area surface to avoid reflections that reduce inspection accuracy.
- Clean the filter with a lint free cloth at regular intervals.
- Check the lamp output with a UV-A light meter on a monthly basis to ensure minimum required output is maintained.

To test a lamp's output, the radiometer (UV-A) detector is placed 400 mm from and normal to the lamp and this value on the light meter is recorded. The detector is then moved vertically and horizontally to determine the stand off distance required to reach the required intensity level of either 0.5 mW/cm2 or 0.8 mW/cm2, and this distance is recorded and used as the inspection standoff distance. All readings are recorded and maintained for comparison with subsequent lamp checks. The environment in which the test is made should be standardized as to ambient light to ensure consistency. As already mentioned, ambient light should be less than 10 lux during the lamp check.

For aerosol penetrant materials, quality checks are not normally required. If an inconsistency is noticed, 1 in each 20 cans should be checked to the applicable ASTM standard.

CLEANING

Cleaning is a requirement before penetrant application. It is also a normal requirement at the completion of penetrant testing. The initial cleaning is usually known as 'precleaning' and will be referred to as such. While each step of the selected technique is of equal importance, without adequate and thorough precleaning of the test area, test results will be of doubtful value. Particular attention by the SCWI to this facet is of vital importance.

Due to the passivity of the method, no penetrant will enter a discontinuity if it contains other materials such as paint, oil, grease or other surface contaminants. Precleaning must thus be aimed at removing visible and other likely impediments to penetrant testing efficiency. For welded fabrications made with new base metals,

precleaning is usually limited to brushing with wire or bristle brushes and a quick solvent clean.

For welds on existing structures or components, paint must be stripped to bare metal; oil and lubricants can be removed with solvent and/or steam cleaning. Hot and/or cold solvent degreasing is common practice. If a more aggressive treatment is required, walnut shell or peach pit meal blasting can be done.

Excessively vigorous mechanical cleaning action may peen the edges of a discontinuity, even to the point of closing it. Care too must be exercised when detergents are used in precleaning; ensure they are suitable for the base metal. Another consideration with any liquid cleaning is to ensure it is fully removed and does not itself fill a discontinuity. As a general principle, penetrants and water should not be allowed to mix or come in contact.

DWELL TIME (Contact Time)

As has been discussed, penetrants take time to enter discontinuities. This time interval is known as the ‘dwell time’ or ‘contact time’. It is the time between the application of the penetrant liquid and the commencement of the removal procedure. It may be as short as a few minutes or as long a half hour or more. However, for many weld testing applications, 20 to 30 minutes is usually enough.

The required dwell time can be influenced by the test piece temperature. As a general rule, the higher the temperature, the faster will be the ingress of penetrant to discontinuities. This is consistent with the previously mentioned topic of viscosity. An elevated temperature does not change the surface tension of the penetrant. Furthermore, if the elevated temperature is high enough to open discontinuities, it would act to reduce capillary pressure.

There is also a risk that penetrant evaporation will become a factor. As penetrants are solutions of various substances, the solutes coming out of solution will be deposited in the very areas where penetrant access is basic to the test. Thus some warming of test pieces may be beneficial in cold weather environments, but should not be adopted as a standard practice.

INSPECTION

An inspection of the test area should be made after cleaning but before penetrant application. Inspection should continue while the penetrant is on the surface to ensure it remains wet. Immediately after developer application, the test surface should be checked for indications. Further inspections of the developer surface should be made and only concluded not less than 30 minutes after developer application.

PENETRANT APPLICATION 'INSTRUCTIONS'

An NDE Instruction may be described as a written description of the steps to be followed in carrying out a test. It must describe the test in sufficient detail to ensure no necessary activities are omitted. An instruction is unique to a test type and each item to be tested. Therefore, the component or fabrication must be identified together with the base metal. Minimum ‘operator’ qualification(s) are to be specified along with such other data as will satisfy quality system provisions.

For PT work, the sequence of events will follow the general format shown below.

1. Preparation, preclean, inspect.
    - Specify cleaning method.
    - How it is to be applied.

2. Apply penetrant, allow dwell time.
   - Specify type of penetrant.
   - How it is to be applied.
   - Specify dwell time.
   - Avoid drying of penetrant
3. Remove excess (surface) penetrant
   - Specify removal system.
   - Give details of application.
   - When to terminate removal.
4. Apply the developer.
   - Specify developer type.
   - Give details of application.
5. Inspect test area over 30 minutes.
   - First inspection immediately.
   - Inspections at selected intervals.
6. Postcleaning of test area and report.
   - Specify extent of postcleaning.
   - Specify method if not apparent.
   - Detail reporting requirements.

Additional provisions should specify what is to be done if any instruction cannot be observed. Applicable codes or standards are to be referenced. If non-conforming indications are identified, describe the action to be taken. The originator of the instruction and the person authorizing the use of the instruction should sign the form giving their qualification/position.

A sample format for NDE Instructions is shown as Form A at the end of this section.

INSPECTION REPORTS

In reporting, the minimum requirements are to provide the following:

Part A - Identification of the document.

Part B - Identification of item/s inspected.

Part C - Results of inspection, including:
- Drawing, to scale, show indications,
- Datum point, clear identification,
- Discontinuities, with type, if known,
- Distance from the datum,
- Discontinuity dimensions.

Part D - Inspector’s name, qualification, date & distribution of report.

A sample format for NDE reporting is shown as Form B at the end of this section.

Of the many possible combinations of penetrant testing, some are preferred in the majority of cases for testing welded fabrications. As mentioned, fluorescent dyes tend to be too sensitive. When used at all, the application tends to come down to just one type. This, and the more usual combinations are detailed below.

Color Contrast (solvent soluble) Penetrant with non-Aqueous Developer

This is the most frequently used system for welds, site work and local area checks. The developer may also be known as ‘solvent suspended’ or ‘liquid spray’.

1. Preparation and precleaning. Precleaning to a documented standard minimizes risk of entrapped residues.
2. Apply penetrant. Use aerosol/spray gun, keep surface ‘wet’ (shiny) during dwell time.
3. Dwell or Contact time. Minimum 10 minutes, normal 30 minutes, usual maximum, 1 hour.
4. Remove excess (surface) penetrant. Wipe with solvent-moistened, lint free cloth or paper wipes. Wipe in a single direction over test area. Continue cleaning until cloth/wipe shows only a faint pink discoloration.
5. Apply developer to test area. Agitate thoroughly, test on redundant surface. Spray from >300 mm, leaving a thin, uniform film on test area. Multiple thin coats are best .

Inspect test area. Inspect immediately after developer application and periodically over suggested maximum of 30 minutes.

7. Clean, and protect if necessary.

Water Washable Color Contrast Penetrant with Non-Aqueous Developer

This system is used when there is suitable waste water disposal. Some risk of penetrant wash-out if water spray is used.

1. Preparation and precleaning. Precleaning to a documented standard minimizes risk of entrapped residues.
2. Apply penetrant. Use aerosol/spray gun, keep surface ‘wet’ (shiny) during dwell time.
3. Dwell or Contact time. Minimum 10 minutes, normal 30 min, usual maximum, 1 hour.
4. Remove excess (surface) penetrant. Wipe with water-moistened, lint free cloth or paper wipes. Wipe in a single direction over test area. Continue cleaning until cloth/wipe shows only a faint pink coloration, or remove most of penetrant with low (< 1 bar) pressure spray, wipe as above.
5. Apply developer to test area. Agitate thoroughly, test on redundant surface. Spray from >300 mm, leaving a thin, uniform film on test area. Multiple thin coats are best.
6. Inspect test area. Inspect immediately after developer application and periodically over suggested maximum of 30 minutes.
7. Clean, and protect if necessary.

Water Washable Color Contrast Penetrant with Dry Powder Developer

Mainly for rough castings, but can also be used for some welded fabrications.

1 Preparation and precleaning. Precleaning to a documented standard minimizes risk of entrapped residues.
2. Apply penetrant. Use aerosol/spray gun, keep surface ‘wet’ (shiny) during dwell time.
3. Dwell or Contact time. Minimum 10 minutes, normal 30 minutes, usual maximum, 1 hour.
4. Remove excess (surface) penetrant. Wipe with water-moistened, lint free cloth or paper wipes. Wipe in a single direction over test area. Continue cleaning until cloth/wipe shows only a faint pink coloration, or remove most of penetrant with low (< 1 bar)

pressure spray, wipe as above ensuring test area fully dry. Hot air blower may be used for final drying.

5. Apply developer to test area. Using ‘puffer’, distribute a thin, uniform film of powder on test area.

6. Inspect test area. Inspect immediately after developer application and periodically over a suggested maximum of 30 minutes.

7. Clean, and protect if necessary.

Water Washable Fluorescent Penetrant and Dry Powder Developer.

This system is most sensitive for both tight and wide, shallow discontinuities. Penetrant removal from rough areas may present a problem.

Stages 1, 2 and 3 as other systems.

4. First stage water wash rinse. A brief pre-rinse with low pressure water (15 to 30°C) spray under UV light leaving faint purple tinge on surface.

5. Apply remover, spray or immersion. Use 5 to 30% aqueous solution, contact time, 3 minutes maximum.

6. Remove excess penetrant. Use water spray as in 5. above, leaving faint fluorescent background.

7. Dry test area surfaces. Hot air, recirculating oven or forced warm air recommended. Normal maximum drying time, 10 minutes.

8. Apply developer to test area. Use a puffer (insufflator) or electro-static or flock spray gun to apply.

9. Inspect test area. Inspect immediately after developer application and periodically over a suggested maximum of 30 minutes.

10. Clean, and protect if necessary.

SUMMARY OF PENETRANT TESTING SYSTEMS

The four systems reviewed above are those most usually applied to welded fabrications. However, on occasions, other systems may offer advantages. Other combinations include solvent removable and water washable fluorescent penetrants although post ‘emulsifiable’ is most common.

A special case, for instance, is for site work, in bright sunlight. It is possible to use a solvent removal fluorescent type penetrant known as ‘dayglo’. This penetrant fluoresces in sunlight. In conjunction with a dry or liquid developer, it has high sensitivity.

Lighting conditions in the areas where penetrant testing is being carried out is a most significant consideration. This applies not only during inspection but also during the other stages of the examination. As previously mentioned, 500 lux in the work area for color contrast penetrants is required. Additionally, it is desirable to view the test area from both the front and at a number of angles.

A considerable amount of welded fabrications are tested using one or more of the penetrant systems noted above. For smaller pieces, the bench unit shown in Figure 4.3.11 is commonly used. In fact, the large bulk of PT is done in bench units, but this approach seldom applies to large weldments.

Instruction Sheet for FORM A Page 1 of 1

Instruction No.

Item to be tested:

Test Method:
Area to be tested:
Test Specification:
Metal specification:
Conformance to:
Other Information
Minimum Qualification of Inspector:
Equipment required:
Stages of Inspection:
Notes: 1. Carefully read all instructions before proceeding
2. Observe all applicable safety precautions
Prepared by (print): Authorized (print):
Sign, qualifications: Sign, qualifications:
Date prepared: Effective date:

Instruction Sheet for FORM A Page 1 of 1
Instruction No.
Item to be tested:
Test Method:
Area to be tested:
Test Specification:
Metal specification:
Conformance to:
Other Information
Minimum Qualification of Inspector:
Equipment required:
Stages of Inspection:
Notes: 1. Carefully read all instructions before proceeding
2. Observe all applicable safety precautions
Prepared by (print): Authorized (print):
Sign, qualifications: Sign, qualifications:
Date prepared: Effective date:

Instruction Sheet for Penetrant Testing Form A
Instruction No. ABC-123, rev.1 Page 2 of 2
Stages of Inspection Continued)
7. Terminate penetrant removal when the cloth shows only a faint pink coloration.
8. Inspect the test area, record any discontinuities observed.
9. Apply a thin, uniform film of developer to the test area, record any indications.
10. Inspect test area immediately and at intervals of 5 minutes for a total of 30 minutes, recording any indications observed.
11. Remove developer from test area by brushing, with solvent if necessary.

12. Complete report, highlight any nonconformances, transmit to NDE Supervisor.
13. Repeat steps 2 -12 after 72 hours.
14. Complete Report.

Prepared by (print): John Smith
Authorized (print): William Brown
Sign, qualifications: J. Smith, AWS PT II
Sign, qualifications: W. Brown, AWS PT III
Date prepared: June 30, 1996
Effective Date: July 15, 1996

NDE Test Report
Form B
Page 1 of 1

Date prepared:
Report No.
Item tested:
Test Method:
Area to be tested:
Test Specification:
Metal specification:
Conformance to:
NDE Instruction No.
Name and Qualification of Inspector:
Equipment used:
Consumables:
Test Details and Results:
Follow-up Required:
Prepared by (print):
Distribution:
Sign, qualification:
Attachments

NDE Test Report
Form B
Page 1 of 2

Report No.: 96-125
Item tested: Test plate, TP - #8, 10 mm, GTAW, 600 V, 2 root/face
Test Method: Penetrant, Color contrast, solvent removable
Area tested: Weld, root and face, HAZ + 25 mm
Test Specification: ASTM E165
Metal specification: ASTM A514
Conformance to: AWS D1.1-96
NDE Instruction No: ABC-123, rev 1
Name and Qualification of Inspector: James Johnson, AWS, PT II
Equipment used: Phillips Radiometer, Model UW2a, Serial 04234, Calibrated 6/10/96

Phillips White Light Sensor, Model W04, Serial 01424, Calibrated 6/1/96

Consumables: Magnaflux Solvent-Remover, Type SR-2, Batch 966201, Aerosol pint can

Magnaflux Penetrant, Type PC-4, Batch 962076, Aerosol pint can

Magnaflux Developer, Type DC-6, Batch 962011, Aerosol pint can

Test Details and Results: Lighting conditions checked before both tests: 1050 - 1200 lux

1. Visual inspection after cleaning; 3 mm transverse crack in weld root, at 80 mm (N/C)
2. First test inspection; star cracks within 4 mm radius in crater, center on 143 mm (N/C) Intermittent undercut < 1 mm, on Side A, (face), 54 to 75, 210 to 250 within spec
3. Inspection after 10 minutes; overlap, 36 mm long, 157 and 193, face side B (N/C)
4. Inspection after 30 minutes; no other indications observed
5. Inspection after 72 hours; original indications confirmed, no other indications observed
6. Test Plate TYP - #8 does not conform to AWS D1.1-96 requirements; see Table 6.1
7. See sketches on sheet 2 attached for location of discontinuities

Follow-up Required: None Note: N/C = nonconforming

Sign, qualifications: James Johnson, AWS, PT Level II

Reporting date: September 25, 1996

Distribution: Q. C. Supervisor

NDE Test Report Form B

Report No.: 96-125

Item tested: Test plate, TP - #8, 10 mm, GTAW, 600V, 2 root/face

```
<Datum (zero) end                    TP - #8                    Face - Weld side A
        (4) UC                       (2) Star cracks (4 mm rad)        (4) UC
    54---------75                   143                 210-----------25-
                                                                     X
                                                     157-----------193
                                                                          OL

        Weld side B
<Datum (zero) end                    TP - #8                    Face - Weld side B
    (1) Transverse crack, 4 mm long
    >1
    80
```

Weld side A

Notes:

UC	=	undercut
OL	=	overlap
X	=	cracks