MEI
The Materials Engineering Institute of
ASM International
Materials Park, OH 44073-0002

American Welding Society

The Materials Information Society

Lesson Number and Title

Welding Inspection & Quality Control

1. The Welding Inspector
2. The Metric System, Welding Terms and Symbols
3. Basic Welding Metallurgy
4. Materials Control, Weld Joint Inspection and Temperature Control
5. Welding, Joining and Cutting Processes - I
6. Welding, Joining and Cutting Processes - II
7. Qualification and Welding Procedures, Welders and Welding Operators
8. Codes Governing Welding Inspection
9. Weldment Imperfections and Discontinuities
10. Chemical, Metallurgical and Mechanical Testing of Welds
11. Visual and Liquid-Penetrant Inspection
12. Magnetic Particle and Radiographic Inspection
13. Ultrasonic Inspection
14. Eddy-Current Inspection, Acoustic Emission, Proof Tests and Leak Tests

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The Welding Inspector

A lesson from WELDING INSPECTION AND QUALITY CONTROL

Course 36
Lesson, Test 1



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Metric Conversion Factors

To convert from	To	Multiply by
in.	mm	25.4
in.	m	25.4×10^{-3}
mil	μm	25.4
μin.	μm	25.4
$in.^2$	m^2	6.45×10^{-4}
$in.^3$	m^3	1.64×10^{-5}
ft.	m	3.048×10^{-1}
$ft.^2$	m^2	9.29×10^{-2}
$ft.^3$	m^3	2.831×10^{-2}
oz.	g	2.834×10^{1}
lb.	kg	4.536×10^{-1}
Btu	J	1.054×10^{3}
Btu/lb. • °F	J/kg • K	4.18×10^{3}
Btu/ft. • hr • °F	W/m • K	1.730
10 in./in./°F	10^{-6} mm/mm/°C	1.8
psi	Pa	6.895×10^{3}
psi	kPa	6.895
ksi	kPa	6.895×10^{3}
ksi	MPa	6.895
ksi • $in.^{1/2}$	MPa • $m^{1/2}$	1.099
ksi√in.	MPa • √m	1.099
oz.f	gf	28.4
lbf	kgf	4.536×10^{-1}
lbf	N	4.448
lbf • ft.	N • m (or J)	1.356
$lbf/in.^2$	kgf/cm^2	14.223
$lbf/in.^3$	kgf/m^3	2.768×10^{4}
$lb./ft.^3$	kg/m^3	16.019
$lb./in.^3$	g/cm^3	2.768×10^{1}
$lb./in.^3$	kg/m^3	2.768×10^{4}
gal (U.S. liquid)	L	3.785
gal (U.S. liquid)	m^3	3.785×10^{-3}
lb./gal	g/L	119.826
ft./gal	ml/L	748
°F	°C	(°F – 32)/1.8
°F	K	(°F + 459.67)/1.8
°C	°F	(°C • 1.8) + 32
°C	K	°C + 273.15
K	°C	°C – 273.15

Multiple and Submultiple Units

10^{18}	exa (E)	10^{-1}	deci (d)
10^{15}	peta (P)	10^{-2}	centi (c)
10^{12}	tera (T)	10^{-3}	milli (m)
10^{9}	giga (G)	10^{-6}	micro (μ)
10^{6}	mega (M)	10^{-9}	nano (n)
10^{3}	kilo (k)	10^{-12}	pico (p)
10^{2}	hecto (h)	10^{-15}	femto (f)
10^{1}	deka (da)	10^{-18}	atto (a)

Abbreviations

J	joule	m	meter	Pa	pascal
kgf	kilogram force	mm	millimeter	K	kelvin
L	liter	N	newton	W	watt

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The Welding Inspector

Inspection of assemblies fabricated by welding involves many factors that cannot be outlined in a code or specification. These factors involve the fundamental principles of the welding operation and process, basic properties of welds and base metals, testing methods and interpretation of drawings and specifications. Furthermore, the inspector often cannot quickly obtain technical information.

These lessons are written in general terms and do not include all of the conditions that may apply to a specific fabrication. The codes or specifications applicable to any one particular weldment always take precedence over the generalized material contained in this course, should any conflict arise between the two.

The text is generally directed towards arc welding. However, the general principles of the inspection and testing functions apply equally well to any weldment fabricated by the other joining processes.

For general information on welding and brazing, the student is referred to the *Welding Handbook, Brazing Manual and Recommended Practices for Resistance Welding*, published by the American Welding Society, and *ASM Handbook*, vol. 6, *Welding, Brazing and Soldering*, published by ASM International.

Upon completion of this lesson, the student will gain general knowledge on the responsibilities and methods of a weld inspector. Topics include:

- Classifications of weld inspectors;
- Standards and communication;
- Inspection criteria;
- Verification of compliance; and
- Brief descriptions of visual, nondestructive, and destructive test methods.

Who is the Welding Inspector?

A welding inspector functions as the judicial representative of an organization, which may be the manufacturer, the purchaser, an insurance company or a government agency. It is the responsibility of an inspector to judge the quality of the product in relation to some form of written specification. An inspector must be able to interpret this specification as to its limitations and intent. Adequate quality must be the goal, but completion and delivery of a project cannot be delayed without proper cause.

The welding inspector is a composite person — a specialist, highly qualified in the field of welding. Inspectors of welding may be classified in the following categories:

- Code or governing agency inspector
- Nondestructive test inspector
- Purchaser, customer or owner's inspector
- Fabricator, manufacturer or contractor's inspector
- Architect engineer's inspector
- Inspectors authorized to inspect in accordance with a national code or standard.

Inspections for the latter category are closely related to the legal aspects of business contracts such as:

Throughout this course, the words *he* and *his* are used as neutral pronouns. This usage is certainly not intended to disregard the many women who contribute to the field of materials science.

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- ASME authorized inspectors holding commissions from the National Board of Boiler and Pressure Vessel Inspectors, including inspectors representing insurance companies or jurisdictional authorities.
- American Bureau of Shipping inspectors.
- U.S. Coast Guard inspectors.
- Military inspectors (Army, Navy or Air Force).
- State welding inspectors representing, for instance, the Department of Labor, Public or Industrial Service Commission, Building Department, Safety Department or Highway Department.
- Municipal welding inspectors representing the Building Commission, Safety Commission or Labor Bureau.

Where governed by codes or similar documents, the inspector's qualifications, duties, and responsibilities usually are well defined. The requirements for, and the duties and responsibilities of nondestructive test inspectors, is covered in a document ASNT TC-1A, which has been prepared by the American Society of Nondestructive Testing (ASNT). Specific requirements for, and duties and responsibilities of purchaser's or fabricator's inspectors generally are defined only in the larger organizations.

For the purpose of this lesson, welding inspectors have been divided into two general categories, the fabricator's quality control inspector and the code or customer's quality assurance inspector.

The fabricator's inspector is part of the manufacturing team and works daily in the production system, in the shop or at the erection site. The primary objective is to assure that the work done is of adequate quality and complies with applicable drawings and specifications. Thus, this inspector is a part of the manufacturer's quality control effort.

The code or customer's inspector is the welding inspector representing a customer — code, government activity, architectural engineer or any other activity outside the manufacturer's organization. His duties normally do not include mandatory surveillance of the actual welding process, although he has the right to look at the production process. The work is more likely to be an auditing function, involving review of records to assure that all of the requirements of the specifications, drawings and other contractual documents have been met. This includes, but is not limited to, a review of the welding process, welder and welding operator qualifications, and welding records including preheat, post-heat, welding variables and conditions, mill test reports on base metals, welding filler material documentation and nondestructive testing reports.

Both types of inspectors must have the ability to deal with and communicate effectively with all levels of management in the manufacturer's organization and in their own organizations. They must be able to reduce their findings into readable and effective reports.

Since both types of inspectors require the same basic skills and know-how, this lesson will deal principally with the duties of the "in-plant" or quality control welding inspector. All of the information contained in this lesson will apply to the quality control welding inspector and, in varying degrees, to the other categories of welding inspectors. In all instances, it is presumed that the inspector has all the qualifications necessary to make proper inspection of the structure in question.

Welding Inspector Qualifications

For a person to become a welding inspector, the following qualifications are necessary. None of these qualifications can be treated lightly by any person who wishes to do his inspection job conscientiously and professionally.

Physical Condition. Inspection conditions are frequently difficult and therefore require excellent physical condition. Because inspection requires examination before, during and after fabrication, an inspector must often climb around large fixtures and assemblies. He must always remember that the work is positioned for the convenience of welders and/or welding operators, not for him.

Vision. Good vision is vital. Inspectors must be able to look closely at welds and at the results of radiographic or other nondestructive tests. An AWS certified welding inspector must have 20-40 vision, as read on corrective eye charts, and Jaeger J-1 near vision acuity, with or without corrective aids (such as glasses).

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Attitude. The importance of a professional attitude cannot be overemphasized; it determines the degree of success or failure. To be successful, an inspector must receive the cooperation of associates in all departments and must command their respect to obtain their help. He must strive to be impartial and consistent in all decisions and must follow a definite procedure of inspection. He should be neither stubborn nor readily swayed by persuasive arguments. And, under no circumstances, should he seek favor or incur obligation through his decisions or through pending decisions.

The inspector will find that the most difficult time is during the first few weeks at a new location. During that time he will be tested for weaknesses in his inspection policy. He should remember that the applicable contract documents define the specific inspection requirements, as well as duties, authority and responsibilities. If he is informed, fair, consistent and follows the intent of the contract specifications, he will earn respect and cooperation.

Knowledge of Welding. The inspector must have adequate knowledge of the welding processes to anticipate what imperfections are likely to occur and where to look for them. He should be familiar with common welding procedures and should know the limitations welders and welding operators have in following procedure details. He should know the essential variables of applicable welding process and should monitor those variables during all phases of construction, as specified by the governing code. He should also be familiar with the common alloys and material grades used in the specific fabrication.

Drawings, Specifications and Procedures. The inspector must be familiar with engineering drawings and be able to interpret specifications. He must read and understand drawings and must know the welding and nondestructive test symbols. Sometimes, decisions must be made about welds that were not detailed in the specifications or drawings. The inspector must then ask for a ruling from a qualified welding engineer or the project engineer.

Copies of the purchase specifications and adequate engineering drawings should be supplied to the inspector as part of the contract. These purchase specifications should include base metal specifications, requirements on welding procedure specifications and the qualification of these procedures, the welders or the welding operators. Also, these specifications should define the number, types and sizes of imperfections and discontinuities permitted in the weldments. The fabricator or contractor should be required to specify the details of the inspection methods to be used. These statements could be in the form of manufacturing instructions to the welding shop and to the field personnel.

Knowledge of Testing Methods. Numerous testing methods are used to determine whether a weld meets a quality standard. Each method has its limitations. The inspector will need to know what each method will show and how to interpret the results. The selected test method must yield adequate information for comparison with previously established acceptance standards.

Records. The inspector should maintain adequate records. He must write concise reports that can be understood without difficulty. Reports should be complete enough so that the reason for his decisions will be clear several months later. Their meaning should be plain to a reader unfamiliar with the product.

The inspector should remember that facts well known at the time of the writing may not be recalled as clearly, completely or accurately later. The records should include not only all results of inspections and tests but also the records of the welding procedure, welding procedure qualifications and control of welding materials. Good records protect his reputation as an inspector and help in writing a concise, complete report. Additionally, if it is clearly written, it will be understood and appreciated by a reader who is unfamiliar with the nature of the work that is being discussed.

Welding Experience. Actual experience as a welder or welding operator is invaluable to an inspector. Welding experience broadens his welding knowledge, commands respect, and gives him more credibility when asked to offer constructive criticism after rejecting poor work. Wide variations in experience and training are found in successful welding inspectors. Minimum requirements have been established by the American Welding Society (AWS) as a framework applicable to widely varying preparations. Some employers require their welding inspectors to have welding experience.

Education and Training. Formal training in fundamental engineering and metallurgy is valuable, but many excellent inspectors have obtained equivalent knowledge through experience and self-study.

The American Welding Society has established a certified welding inspector program which requires

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minimum levels of education and experience. An AWS certified welding inspector has also successfully completed a six-hour examination on all phases of visual welding inspection. A high school diploma or an approved high school equivalency diploma satisfies the education requirement. Lacking a high school diploma, an inspector may offer an additional five years of qualifying work experience as a substitute. The experience offered must have been closely related to welding inspection. Formal education beyond high school may be substituted for up to two years of experience in welding inspection.

Inspection Experience. A good inspector develops a distinct way of thinking and working and acquires a good professional attitude and broad point of view through inspection experience. Experience in inspecting materials other than weldments also will assist him in the inspection of weldments. Those in training should observe the behavior of experienced inspectors.

To comply with the experience requirement required for AWS certification, the applicant must show evidence of having performed the functions of a welding inspector or other job functions that have a close relationship to welding inspection. Periods of qualifying experience will be counted by the actual number of calendar months employed at jobs (not employers) that had a close relationship to fabrication of weldments according to a code, standard or specification. These jobs should also have included at least one of the following qualifications:

1. Consisted entirely of welding inspection;
2. Included welding inspection as one of the principal job functions; and/or
3. Had a close relationship to welding inspection.

Figure 1 summarizes the qualifications of a welding inspector.

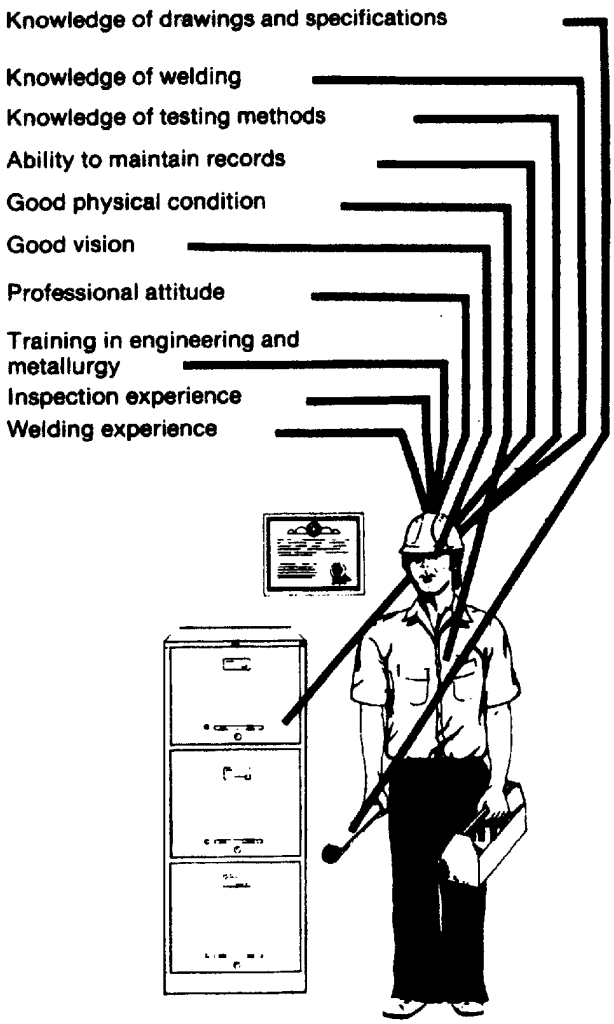


Figure 1. Summary of the qualifications of a welding inspector.

Code of Ethics

The welding inspector must recognize that he has an obligation not only to his employer but, in a broader sense, to the public whose safety may depend on the effectiveness with which the inspector does his job.

To maintain integrity and high standards of skills, practice and conduct in the occupation of welding inspection, the AWS Certified Welding Inspector shall be cognizant of the following principles and the scope to which they apply. Any unauthorized practice is subject to the AWS Qualification of Welding Personnel Committee's review and may result in suspension or revocation of certification.

Integrity. The welding inspector is obligated to act with complete integrity in professional matters and to be forthright and candid on matters pertaining to his job.

Responsibility to the Public. The welding inspector is obligated to perform the duties required of weld in-

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spection in a conscientious and impartial manner to the full extent of his moral and civic responsibilities and qualifications. Accordingly, the welding inspector shall:

1. Undertake and perform assignments only when qualified by training, experience and capability.

2. Be completely objective, thorough and factual in any written report, statement or testimony of the work and include all relevant or pertinent information in such communiques or testimonials.

3. Sign only for work that he has inspected or for work over which he has personal knowledge through direct technical control.

4. Neither associate with, nor knowingly participate in, a fraudulent or dishonest venture.

Public Statements. The welding inspector will issue no statements, criticisms or arguments on weld inspection matters connected with public policy which are inspired or paid for by an interested party without first identifying them and disclosing any possible pecuniary interest.

The welding inspector will publicly express no opinion on a weld inspection subject unless it is founded upon adequate facts in issue, upon a background of technical competence pertinent to the subject and upon honest conviction of the accuracy and propriety of the statement.

Conflict of Interest. The welding inspector shall conscientiously avoid conflict of interest with the employer or client and will disclose any business association, interests or circumstances that might be so considered.

The welding inspector shall not accept compensation, financial or otherwise, from more than one party for services on the same project, nor for services pertaining to the same project, unless the circumstances are fully disclosed and agreed to by all interested parties or their authorized agents.

The welding inspector shall not solicit nor accept gratuities, directly or indirectly, from any party, or parties, dealing with the client or employer in connection with the welding inspector's work.

The welding inspector shall not inspect, review or approve any work on behalf of another party, or parties, while serving in the capacity of an elected, retained or employed public official.

Solicitation of Employment. The welding inspector shall not pay, solicit or offer, directly or indirectly, any bribe or commission for professional employment with the exception of the usual commission required from licensed employment agencies.

The welding inspector shall not falsify, exaggerate, nor indulge in the misrepresentation of personal academic and professional qualifications, past assignments, accomplishments and responsibilities, or those of his associates.

Unauthorized Practice. The Administrative Procedures Manual covers the complaint process regarding violations of the Code, or any unethical practice related to the welding inspector's occupation covered by this Code shall be deemed an unauthorized practice upon the complainant's adherence to the Administrative Procedures Manual for handling complaints and ruling of the Committee.

General Comments

Some manufacturers or fabricators consider a welding inspector a necessary evil which comes along with the job. The view is shortsighted. The normal chain of events will soon demonstrate the value of welding inspection in producing sound weldments at minimum cost (through avoidance of rework and repair).

Nevertheless, that adverse attitude may lead to efforts to bypass inspections or to unethically influence the inspection. At the other extreme, helpful modifications in construction techniques may be requested that could improve output quality or quantity. What should the inspector do?

The inspector walks a two-way street where decisions must be made promptly while remaining impartial but tolerant of the opinion of others. When design or process changes are desired by the production group, as they frequently are, the welding inspector should refer the request to the responsible engineering or contract person. The inspector cannot accept changes to contractual documents by means other than a formal engineering change.

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Communications

A welding inspector must not only possess the physical, technical and ethical qualifications mentioned earlier, but also must possess the skill of a communicator. He must be able to establish lines of communication with associates to accomplish his tasks and responsibilities efficiently and professionally. These associates, for a fabricator's inspector, usually will include one or more of the following: supervisor, welders, welding foreman or supervisor, shop or field superintendent, plant or project manager, project engineer or welding engineer.

Reporting Supervisor. Every inspector will report to someone. In some cases it will be the chief inspector. In other situations it could be the project engineer, a plant manager, an architect, a government official or the manager of quality control or quality assurance.

Welders. The relationship between the inspector and the welder is of utmost importance. The welder often knows which welds were borderline and where the joint fit-up was improper or not as specified. A welder who looks on the inspector as an enemy is not concentrating on making each weld a good one. At any rate, he will not be trying to make the inspector's job any easier. In most instances, there is good rapport between the inspector and welder.

Welding Foreman or Supervisor. The welding foreman or supervisor is highly important to the inspector. Given a group of welders equally qualified to meet specifications, the foreman decides which welder to assign to the more difficult welds. On repairs, the fabricator's representative may suggest that the inspector "Tell the welder what you want," which would make the inspector a party to the act. Remember, an inspector's authority extends only to pronouncing the weld accepted or rejected. Cordial communication with the foreman smooths the path of making acceptable welds.

Shop or Field Superintendent. The shop and field superintendents push the foreman for production. Their confidence in the inspector will forestall efforts to bypass any required inspections.

Plant Manager. The plant manager also feels production pressures and may similarly wish to bypass inspection requirements. The inspector needs to keep him informed, to assure him that the requirements are being met as scheduled.

Project Engineer. The project engineer is the prime interpreter of the drawings and specifications for the job. Usually, these documents represent his detailing of each joint to meet the design engineer's intentions. An overview of the job in consultation with the project engineer will bring out any tasks that need extra planning. For example, at a multiple connection, weld sequencing may be needed to assure sound joints, or a revision in design and detailing may facilitate meaningful inspection.

Welding Engineer. The welding engineer approved the materials chosen by the design engineer. An inspector needs to have access to the welding engineer so that possible construction problems can be brought to the engineer's attention before they become inspection problems.

Communicating is critically important to the inspection process. The primary function is to inspect the fabricator's work to see that it meets the requirements of the contract. How the work is proceeding is the substance of an inspector's reports. Whether the fabricator takes advantage of that information may depend on how clearly it is phrased. The fabricator still has full responsibility for the quality of the final product.

Proper communications will allow an inspector to keep in touch with the activities of the production organization. Early correction of a fault results in producing a satisfactory product instead of one that might otherwise have to be rejected.

Welding Inspector Responsibilities

The welding inspector holds a position of responsibility. This responsibility demands a professional person with good character, ability and common sense. A welding inspector may work at various fabrication plants and at various job sites. In all instances, he should observe the working hours of the fabricating organization. Strict observance of all rules and regulations is mandatory, especially those pertaining to personal conduct, safety and security. At no time should he consider himself entitled to special privileges. In dealing with the fabricator organization, he should be impartial, render decisions promptly and be tolerant of the opinion of others during communications. He should remember, however, to stick to the facts in making decisions and not be easily swayed by differing opinions.

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An inspector's primary function is to inspect the fabricator's work to ensure it meets the requirements of the contract. This will require keeping in touch with the activities of the fabricator's production organization.

The duties of an inspector for most types of fabrication will follow the general order of the fabrication procedure. A welding inspector will have the responsibility to:

- Interpret all weldment drawings and specifications;
- Check purchase orders to assure that weldment materials and consumables have been properly specified;
- Check and identify base and welding filler materials as they are received against the purchase specifications;
- Check the chemical compositions and mechanical properties shown on mill test reports against specified requirements;
- Investigate base metal imperfections and deviations;
- Check storage of filler materials;
- Check equipment to be used;
- Check weld joint preparations;
- Check joint fit-up;
- Verify the application of the approved welding procedure;
- Verify the qualification records for the welding procedure, welders and welding operators;
- Select production test samples if required;
- Evaluate the test results against the specification;
- Maintain records; and
- Prepare reports.

In many instances, the shop inspector may not be required to perform all of the duties listed above. However, if he does not do this personally, someone else in the organization does this work, and it is a reasonable assumption that the quality assurance inspector (outside inspector) will examine most of these areas.

Knowledge of Drawings and Specifications. The inspector should study the drawings and designs in advance to familiarize himself with the construction details, the proposed use of subassemblies and the specifics of the welding operation. He should note the materials to be used in the welded structure and if any of them require special treatment for satisfactory welding. This information should be clearly stated in the specifications or welding procedures. If it is not there, he should talk to the project engineer.

During fabrication of a welded structure, he will be called upon to interpret drawings and specifications. Prior study of the drawings and design will enhance his ability to make clear and concise decisions. Clear and concise decisions will speed completion of the work under contract, increase his professional image and greatly aid in exercising authority.

Situations that require a deviation from the drawing or detailed specification may arise during the fabrication of any structure. It is his responsibility to bring the deviation to the attention of the project engineer or quality assurance manager, and ask whether the deviation will be accepted or not. Sometimes, acceptance or rejection of a large welded structure will be involved. In all instances, extreme caution should be exercised in accepting deviations. Deviations from drawings must be referred to the design agency for approval and process deviations can only be made by the responsible engineering organization. It is not always possible to write an all-inclusive specification containing all the detailed information needed to provide an answer for any question that might arise. If the specifications have requirements that are not fully defined, the inspector is often responsible for determining the meaning and intent of the specification through discussions with the project engineer. In case of disagreement, the question should be returned to the engineering department.

If design changes and manufacturing process deviations become necessary during manufacturing or erection, it is desirable to have a formalized method of handling such deviations. This is necessary to assure efficient correction of the nonconforming item or acceptance of the deviation by the appropriate engineer-

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ing and contract group. This procedure also provides the inspector with a record of the occurrence.

Purchase Specifications Check. The specifications for the job should identify all the materials that will be used. This list should include all base metals, and all consumable materials such as welding electrodes, inserts, welding or brazing fluxes, shielding gases and backing bars and rings. The inspector should examine the purchase specifications to assure that the materials ordered are the required materials. For example, commercial specifications for steel, such as ASTM A572, frequently include more than one grade of the product, which must be individually identified on the purchase order to obtain the correct grade. As another example, specifications for welding electrodes, such as AWS A5.1, will cover a dozen or more electrode grades in the one document. In A5.1, the six E70XX electrodes are all equivalent in strength, but they are not interchangeable when low-hydrogen grades are required. In that event, E7015, E7016, E7018 or E7028 must be called out on the purchase order.

Job Material Verification. Mistakes do happen. Many metals look alike, leading to the possibility of inadvertent mix-ups. To prevent this, the inspector must verify that the materials supplied match a purchase order and are identified visibly on each piece, preferably at multiple locations on each piece. Identification is lost for the remainder of the plate if the first slice cut off by the shop removes the labeled end with the grade stamp on it. Good practice calls for restamping remnants produced in cutting operations at the time of the cut while the identity is still known. Quality assurance regulations of the American Society of Mechanical Engineers require witness and verification of this operation by an inspector.

Identification of low-hydrogen welding electrodes is sometimes lost when stockroom clerks remove electrodes from their containers to store them in holding ovens. The individual electrodes will have classification numbers on their coverings (at the stub end), but the manufacturer's control number only appears on the container. In nuclear and other critical work, that control identification will be needed for each weld. The best storage place for a welding electrode, before it is used, is its original unopened container.

Filler Metal Identification. The American Welding Society has developed a system of filler metal and flux identification that is simple, readily usable and of considerable help to the inspector. Figure 2 describes the AWS designation.

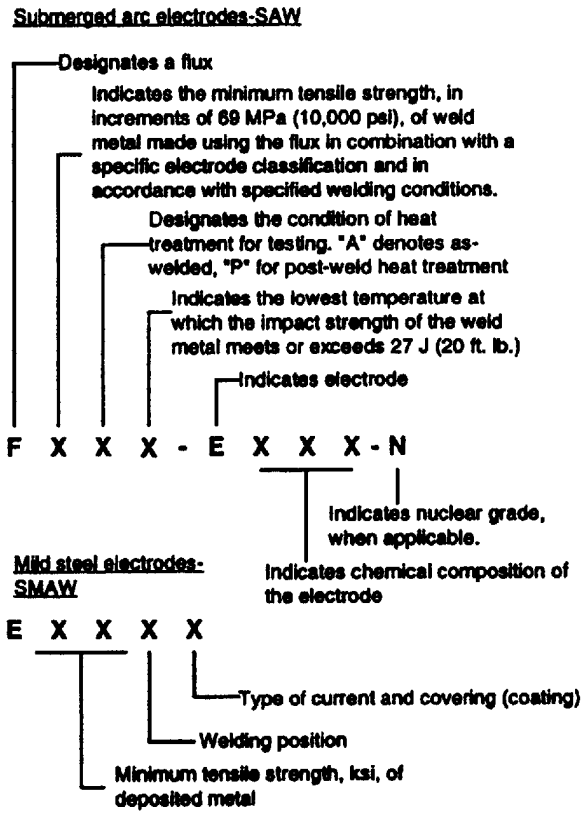


Figure 2. Examples of the ANSI/AWS electrode designations; top electrode is for submerged arc welding (SAW) which requires a flux. The bottom electrode denotes an SMAW covered electrode for carbon steel.

Storage of Filler Materials. The welding inspector should especially investigate how welding electrodes and filler materials are stored. Low-hydrogen electrodes out of their containers must be kept in holding ovens at the proper temperature prescribed by the electrode manufacturer or applicable specification. Keep in mind the necessity for preserving lot identification for nuclear jobs. Also remember that fluxes and flux cored electrodes need protection from moisture, whether it be rain or high humidity.

Welding Equipment Check. All welding equipment, including that to be used for testing, should be checked for operational capability, calibration and safety. For example, the inspector should always check the ammeters and voltmeters. These meters on welding machines may not be accurate because of mistreatment, dirt, grime and overloads. Periodic calibration may be necessary.

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Table 1. ANSI/AWS A5.1 Specification Noting Electrode Currents and Coverings for Carbon Steel Electrodes

AWS Classification	Type of Covering	Capable of Producing Satisfactory Welds in Position Shown[a]	Type of Current[b]
E60 Series Electrodes			
E6010	High cellulose sodium	F, V, OH, H	DCEP
E6011	High cellulose potassium	F, V, OH, H	AC or DCEP
E6012	High titania sodium	F, V, OH, H	AC or DCEN
E6013	High titania potassium	F, V, OH, H	AC or DC, either polarity
E6020	High iron oxide	H-fillets	AC or DCEN
E6022[c]	High iron oxide	F	AC or DC, either polarity
E6027	High iron oxide, iron powder	H-fillets, F	AC or DCEN
E70 Series Electrodes			
E7014	Iron powder, titania	F, V, OH, H	AC or DC, either polarity
E7015	Low hydrogen sodium	F, V, OH, H	DCEP
E7016	Low hydrogen potassium	F, V, OH, H	AC or DCEP
E7018	Low hydrogen potassium, iron powder	F, V, OH, H	AC or DCEP
E7024	Iron powder, titania	H-fillets, F	AC or DC, either polarity
E7027	High iron oxide, iron powder	H-fillets, F	AC or DCEN
E7028	Low hydrogen potassium, iron powder	H-fillets, F	AC or DCEP
E7048	Low hydrogen potassium, iron powder	F, OH, H, V-down	AC or DCEP

[a] The abbreviations, F, V, V-down, OH, H, and H-fillets indicate the welding positions as follows: F = flat, H = horizontal, H-fillets = horizontal fillets, V-down = vertical down, V = vertical, OH = overhead. For electrodes 4.8 mm (3/16 in.) and under, except 4.0 mm (5/32 in.) and under for classifications E7014, E7015, E7016, and E7018.
[b] The term DCEP refers to direct current, electrode positive (DC reverse polarity). The term DCEN refers to direct current, electrode negative (DC straight polarity).
[c] Electrodes of the E6022 classification are for single-pass welds.

Weld Joint Preparation. Specific tolerances are listed for weld joint preparations in all codes and specifications. The pre-qualified joints of AWS D1.1 are typical examples. An inspector's responsibilities include examination of the unwelded joint for edge preparation, root face dimensions and bevel angle(s).

Joint Fit-up. Again looking at the unwelded joint, he should observe the fit-up of the parts. For butt welds, alignment (high-low) and root opening are most important. Keep in mind that pre-stressing or cambering may be needed for welds that will be subject to distortion as a result of shrinkage stress. The fabricator should not attempt such welds without the necessary know-how. Procedure modifications may give an acceptable weld, but suggestions should be offered to the project engineer, not to the foreman. If the foreman later says, "You told me to do it this way," the inspector has more difficulty in turning down an unacceptable result.

The fit-up of backing preparations needs particular attention. Bars and straps should fit snugly. No transverse joints between segments of a long back-up bar are permissible, because they can induce cracks in the root pass. The AWS Structural Welding Code (AWS D1.1) requires that steel backing on all groove welds be made continuous for the full length of the weld.

Chemical Analyses and Mechanical Properties Tests. The inspector should request tests on representative samples of critical incoming materials to verify chemical composition and mechanical properties. Where material test reports from reliable suppliers (that is, suppliers accredited through a quality assurance plan or specification) give assurance of conformance, yet errors are strongly suspected, check tests should be ordered.

Material Quality Check. The quality of mill products supplied for a job must match the quality specified for the final weldment or structure. Base metals almost always contain many small discontinuities. In some instances, they may be cause for rejection; in others, they may not. For example, when rolling an ingot to produce a thick plate, a steel mill has less opportunity to break up cast structures, rebond shrinkage cracks and disperse laminations than when rolling a thin plate or sheet. Forgings of all sizes may display splits, tears and surface irregularities. Any product may have objectionable surface irregularities. This includes deviations from flatness, which must be within

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certain limits to meet the requirements of some codes and specifications.

The welding inspector has the responsibility to be sure that discontinuities in the base metal are detected, identified, evaluated and repaired, where necessary, so that they will not be incorporated into the welded product. At times, he may need to communicate with the responsible engineer in deciding what to do about a major defect.

Remember, all specifications state that a defective piece must be rejected and replaced unless it can be repaired. In fact, some imperfections may require rejecting the piece altogether. On the other hand, flame straightening of beams accidentally bent in shipping or handling is commonly permitted. As another example, laminations will rule out placing a plate where it must withstand tensile stresses in the through-thickness direction, but other locations may be found where the same plate may be used with complete safety. The inspector must then obtain agreement from the project engineer that the original defect is not harmful in the new location.

Welding Procedure Qualification. The fabricator must prescribe the details of the welding procedure that will be followed in producing weldments. They should produce welded joints with acceptable mechanical properties as required by the particular specification or code. Lesson 6 describes the elements of a welding procedure specification, the reasons for its use, its qualification and the responsibilities of the welding inspector in verifying welding procedure on the job site.

Welder and Welding Operator Qualification. Codes and specifications that apply to the fabrication of weldments usually require qualification of all welders and welding operators. It is the inspector's duty to verify that every welder and welding operator who works under the code or specification has been properly qualified according to the code. Again, verification is obtained either by personally witnessing each test or reviewing verified results of tests. Thus, an important duty is to limit welders and welding operators to work within their qualifications.

Welding codes or specifications do not normally require re-qualification of procedures, welders or welding operators for each new contract or change of design. However, the requirements of the specification or code must be interpreted to make this determination. Remember that the main objective of qualification tests is to ensure that qualified procedures and welders or welding operators are being used properly. To avoid wasted time and effort, the inspector should not require any unnecessary qualification tests.

Selection of Production Test Samples. In welded assembly, inspection of the product is often performed on samples taken from the production line. These samples may be selected by chance or according to an established order. In either instance, witnessing their selection and testing is an important duty. Sometimes selection of samples is left to the inspector's judgment and discretion. He should not take more samples than will be reasonably needed to determine conformance. Typical tests include radiography and other nondestructive tests, hydrostatic tests, chemical analysis, metallurgical examination and mechanical testing to destruction. He must be sure that such work is properly carried out, and that adequate records are maintained on all test results. Various sampling plans, test processes and inspection methods are described in this lesson and other lessons of the course.

Evaluation of Test Results. Sometimes it will be impractical to witness all tests. However, enough should be witnessed to assure that the tests are being performed in the proper manner and the results are accurate. The inspector makes sure that the testing equipment has been calibrated and is accurate. When the tests have been performed, he must evaluate the results and decide if the product meets the specifications. If the product does not meet the standards for acceptance in certain details, he should consider the overall results against the requirements before deciding on acceptance or rejection. That final decision, unless otherwise specified, is made by the welding inspector.

Maintaining Records and Reports. Code work always requires record keeping. Whether other jobs call for it or not, complete records should be kept by every inspector. Records should be dated, typewritten or completed in ink, be as detailed as necessary, and signed by the inspector. Errors are not to be erased or obliterated but are to be single-lined out in ink, dated, and initialed by the inspector.

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Verification of Compliance

Compliance of the weldment with all applicable specifications is required before acceptance by the purchaser. Depending on the specification requirements, the inspector relies on one or more of the following:

- Visual examination of the weldment;
- Nondestructive examination, usually by a qualified technician;
- Chemical analysis;
- Metallurgical examination;
- Mechanical testing by a qualified laboratory; and/or
- Verification of the procedure, welder and welding operator qualification.

The types and extent of inspection are given by the governing code, engineering standards or job specifications. The inspector cannot accept less and should not ask for more than required by these documents.

The welding inspector should be provided a written welding procedure (process or manufacturing outline) that identifies fabrication, welding and inspection sequences. Such a procedure effectively organizes the work of the inspector an permits a logical sequence of steps to verify compliance.

Weld Inspection Characteristics

There are two types of characteristics that an inspector will look for during his inspection of a weldment. These are attributes and variables.

Attributes. Inspection by attributes treats a weldment as being either non-acceptable (defective) or acceptable (non-defective). This involves reading a scale or using a go/no-go gage to determine if the individual dimensions of a weldment conform to specifications.

Variables. Inspection by variables treats the numerical magnitude of the characteristics under consideration. Acceptance criteria are based on the size and/or number of imperfections found in the weldment, based on the applicable code or specification. For example, the ASME code, Section VIII, contains porosity charts showing the acceptable levels of porosity based on plate thickness, porosity size and distribution as shown by radiographic inspection.

Selecting a Sample

Every sample taken should be representative of the lot because the quality of the lot will be judged by the quality of the sample. (The sample in this instance comprises the weldments or lengths of weld selected for inspection purposes.) The most representative sample is one in which every weldment in the lot, or inch of weld in the weldment has an equal chance of being selected for the sample. If the sample is chosen at a specific interval, such as every twenty-fifth weldment or inch of weld, the other twenty four have no chance of being chosen. Special care may have been taken in making this sample, and thus it would not have been representative.

The entire sample should not be taken from one part of the lot. A good plan is to take a few samples from different parts or areas of the lot. Beware of sampling bias if you have a lot in which some pieces or areas are obviously defective. For instance, if weld appearance is important and there is a lot in which some parts or areas are obviously blemished, it is difficult to sample this lot fairly.

Welds that are in critical locations or critical dimensions of weldments may require 100% inspection. The entire weldment or all of the welds may not need inspection, only those areas listed as critical in the job specifications.

Visual Inspection

Visual inspection usually includes examining the weldment for workmanship and overall dimensions. The welds are examined to assure that their location and size are as specified on the engineering drawings and appearance is as called for in the specifications.

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One requirement of the documents may be that the surface appearance of the welds must match some workmanship standard. The standard may be a prepared specimen, or the standards may be described in writing. A typical workmanship standard for grooves and fillet welds is illustrated in Figure 3.

Engineering drawings generally designate the dimension of the weldment and the dimensions and locations of every weld. Acceptance of the weldment is based on the conformance of each weld with the drawings, which the welding inspector can determine during visual inspection, using gages, scales, calipers or micrometers. Visual inspection may include the use of magnifiers and optics such as borescopes and measuring reticles (magnified). The quality of a weld is, to a large degree, displayed in its surface appearance. When the preparation of the weld joint is good and the welder has the requisite ability, the odds favor a good-appearing weld as being sound and within specification. Visual inspection is discussed in Lesson 11.

Nondestructive Tests

Nondestructive tests on the weld will be conducted by nondestructive testing technicians, as required by the governing documents.

Liquid penetrant inspection can reveal cracks, imperfections and porosity open to the surface. The dye penetrant and the fluorescent penetrant methods are covered in Lesson 11.

Radiographic examination can reveal surface and internal discontinuities by their absorption or transmission of X rays or gamma rays, made visible on photograph film or paper. Radiographic inspection is covered in Lesson 12.

Magnetic particle inspection (see Lesson 12) highlights discontinuities at or near the surface of magnetic materials. The powder may be colored for greater visibility, or coated with a fluorescent dye to be viewed under ultraviolet light, with improved sensitivity. The process uses both wet and dry particles, depending on part size.

Ultrasonic examination can detect surface and internal discontinuities by reflecting high-frequency sound waves. Various techniques include the use of longitudinal waves, shear waves, pitch-and-catch between two transducers, or more commonly a pulse-echo circuit with just one transceiver (a transducer and receiver in one crystal). Indications are displayed on a cathode ray tube. A description of ultrasonic inspection will be found in Lesson 13.

Eddy current testing uses electromagnetic fields to detect discontinuities. This nondestructive inspection method is covered in Lesson 14.

Destructive Tests

Qualification tests for procedures involve cutting apart a prescribed test weld and performing tension

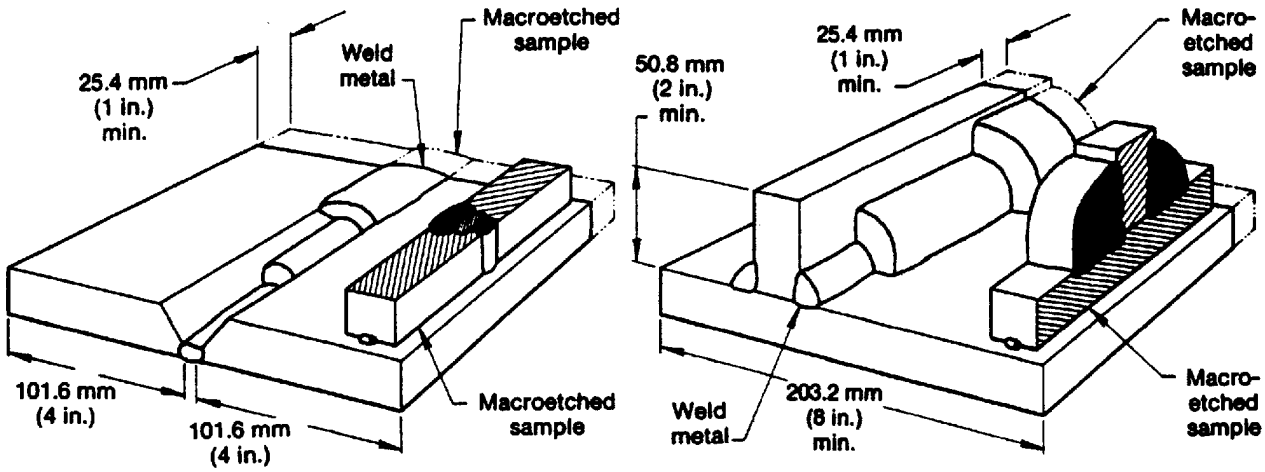


Figure 3. Typical workmanship standard for single-V-groove (left) and fillet welds (right).

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and bend tests on the pieces. Sometimes impact tests and chemical analyses are required.

Qualification tests for welders, tackers and welding operators may include bend tests in some specifications (notably the AWS Structural Welding Code). A macrotech test is also included in that code.

Certification of welding electrodes, filler metals or base metals may require obtaining chips or drillings for chemical analysis of base metals and weld deposits to confirm their chemical compositions.

On the production job, destructive tests may be planned in advance by providing run-off tabs at the ends of critical welds. The tabs can be cut off and examined by the chemical, metallurgical and mechanical testing laboratories, with no damage to the weldment. Such weld extensions provide specimens for chemical analysis, macro and micro examinations, tensile bars, bend tests, corrosion tests, impact tests, fatigue tests and hardness tests.

Indicated Discontinuities. The results of nondestructive tests of a completed weld may indicate discontinuities or imperfections within the weld. Since the inspector cannot accept a weldment that does not meet the requirements of the applicable code or specification, the discrepant area will be marked for repair. Unfortunately, the NDE indication may not tell the welder, the nondestructive testing technician or the inspector sufficient information about the nature of the discontinuity. Usually, the discontinuity must be identified in order to know how to repair it. A crack may extend further than indicated by the nondestructive examination. An inclusion may be associated with a lamination that was otherwise undetected. A fissure may have limited extent, or may be associated with shrinkage discontinuities. Lack of fusion may have been intermittent throughout the section disclosed.

When important, though the cost may be increased, the inspector may request that removal of the discrepant area be accomplished in steps, with the workman looking for signs of the imperfection as the metal is removed. Grinding, chipping or air carbon-arc gouging often gives an observant workman a glimpse of the imperfection as his tool moves past it. These methods are often too coarse to reveal small imperfections, however.

In more critical applications, the inspector will mark the spot to have a section removed from the weldment for thorough examination. A milling cutter or abrasive cutoff wheel may be used to remove a boat-shaped specimen, leaving a groove that may be repaired by rewelding. The section, identified properly, can be sent to the metallographic laboratory for careful examination, looking for the slag, porosity, inclusion, fissure, cracks, lack of fusion or incomplete penetration that initiated the nondestructive indication.

Proof tests are performed on completed weldments, subjecting them to loads above those they are expected to carry in service (Figure 4). Leak tests also are performed on completed weldments. Acoustic emission monitoring may be conducted on partially or fully completed weldments. These methods are discussed in Lesson 14.

Inspection Standards

MIL-STD-105, Sampling Procedures and Tables for Inspection by Attributes; MIL-I-45208, Inspection System Requirements; NAVSHIPS 0900-003-9000, the radiographic standard for production and repair welds; MIL-Q-9858 on quality systems and MIL-W 10430 on the preparation of welding rods and electrodes for delivery are but a few of the specifications and standards on inspection issued by the United States Department of Defense. Generally, these standards are cited in the specifications. Also, there are Federal Standards for inspection such as FED-STD 151, Metals; Test Methods.

The American Society for Testing and Materials has standards that frequently are listed in specifications. ASTM test methods for welds are given in Table 2 and for chemical analysis, Table 3.

The AWS specifications for electrodes and welding rods contain descriptions of all required tests. In addition the AWS has published:

A4.2 Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic Stainless Steel Weld Metal

B3.0 Standard Qualification Procedure

B4.0 Standard Methods for Mechanical Testing of Welds

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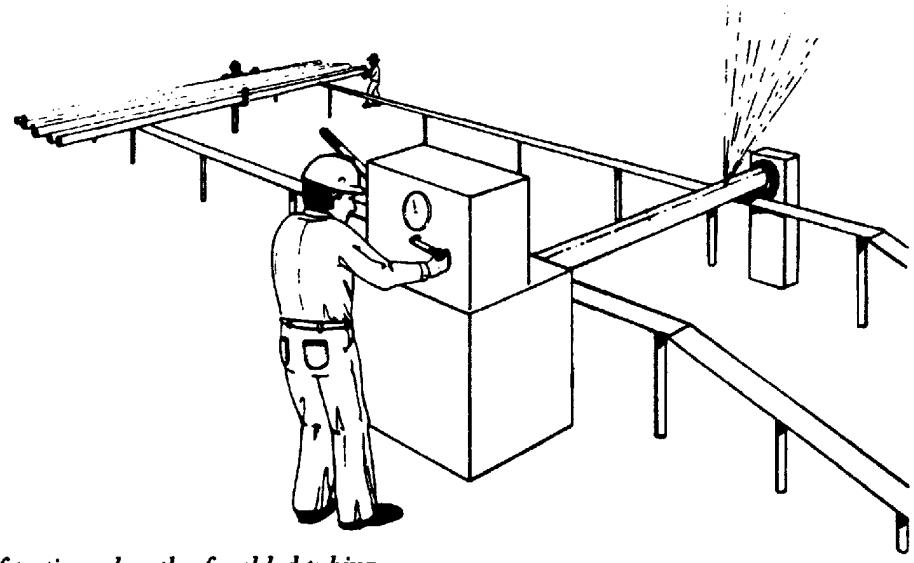


Figure 4. Proof testing a length of welded tubing.

C3.2 Standard Method for Evaluating the Strength of Brazed Joints

D10.9 Standard for Qualification of Welding Procedures and Welders for Piping and Tubing.

Table 2. ASTM Test Methods for Welds

E883	Guide for Metallographic Photomicrography
E340	Macroetching Metals and Alloys
E407	Microetching Metals and Alloys
E4	Verification of Testing Machines
E6	Mechanical Testing Terms
A370	Mechanical Testing of Steel Products
E10	Brinell Hardness of Metallic Materials
E18	Rockwell Hardness of Metallic Materials
E92	Vickers Hardness of Metallic Materials
E110	Portable Hardness Testers
E140	Standard Hardness Conversion Tables for Metals
E8	Tension Testing of Metallic Materials
E23	Notched Bar Impact Testing of Metallic Materials
E190	Guided Bend Test for Ductility of Welds
E208	Drop-Weight Test for Nil-Ductility Transition Temperature of Ferritic Steels
E604	Dynamic Tear Energy of Metallic Materials
E165	Liquid Penetrant Inspection Method
E709	Practice for Magnetic Particle Examination
E164	Ultrasonic Contact Examination of Weldments
E273	Ultrasonic Inspection of Longitudinal and Spiral Welds of Welded Pipe and Tubing
E94	Radiographic Testing
E390	Reference Radiographs for Steel Fusion Welds
G4	Conducting Plant Corrosion Tests
A262	Detecting Susceptibility to Intergranular Attack in Stainless Steels

Table 3. ASTM Standards for Chemical Analysis

E30	Chemical Analysis of Steel
E34	Chemical Analysis of Aluminum
E118	Chemical Analysis of Copper.Chromium Alloys
E120	Chemical Analysis of Titanium
E212	Spectrochemical Analysis of Plain-Carbon and Low-Alloy Steel
E322	Spectrochemical Analysis of Low-Alloy Steels
E327	Spectrochemical Analysis of Stainless Type 18-8 Steels
E403	Spectrochemical Analysis of Plain-Carbon and Low-Alloy Steel

Repairs

In the AWS Structural Welding Code, repairs are considered to be corrections. The option of repairing an unacceptable weld, or removing and replacing the entire weld, belongs to the contractor, not to the inspector. Directions for making such repairs are spelled out in the AWS Code. The repaired or replaced weld is reinspected by the original method and to the same performance standards. However, repair procedures in some codes are more stringent than the original welding steps.

Interpretation of Test Information

The basic rules for interpretation of test data are given in the governing codes. For example, the AWS

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Structural Welding Code tabulates the minimum acceptance levels in decibels for large, small and minor reflections detected in ultrasonic inspection. The discontinuities are noted as indications seen on the cathode ray tube, and are scanned with the search unit to observe their lateral extent (large, small or minor) and their internal position within the weld. The smaller the discontinuity, the larger the decibel level needed to show the blip on the screen. If the indicated spot is to be considered an acceptable discontinuity, its decibel rating must be at least as high as the value in the table, and its length must be within the limits shown.

ASTM specifications give rules for interpreting mechanical tests. The minimum value, maximum value or a range of acceptable values is usually given for each property tested. The inspector interprets the data as meeting or failing to meet these criteria.

The specification should be explicit about the acceptance levels required, but it is possible that the levels may not have been made clear. The inspector then needs to communicate with the quality assurance manager, welding engineer or project engineer to establish the correct interpretation of the test data.

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American Welding Society

WELDING INSPECTION AND QUALITY CONTROL HOMESTUDY COURSE

Please print your name and address below:	Return to:
Name:_____ Address: _____ City: _____ State: _____ Zip: _____	American Welding Society 550 NW LeJeune Rd. Miami, Florida 33126 Attn: Education Dept.

Quiz #1 -The Welding Inspector

1. Which one of the following tests detects discontinuities by the use of reflecting high frequency sound waves?

   (A) mechanical testing
   (B) eddy-current testing
   (C) magnetic-particle inspection
   (D) ultrasonic examination

2. For work governed by codes, an inspector's qualifications, duties and responsibilities are usually:

   (A) not considered important if he or she has a good educational background
   (B) determined by the designer
   (C) well-defined by the code
   (D) not defined if the fabricator uses only AWS-certified welding instructors

3. What is the minimum educational level necessary to become an AWS-certified welding inspector?

   (A) at least two years of college
   (B) none, with qualifying work experience
   (C) graduation from an accredited welding school
   (D) an engineering degree

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4. Where is the inspector told which welds to inspect?

(A) in the written job specifications
(B) the inspector instinctively knows which ones to inspect
(C) labor contract with local trade union
(D) welding foreman or welding supervisor indicates which welds are questionable

5. Samples of a lot should be taken from:

(A) only one part of the lot
(B) different parts or areas of the lot
(C) defective areas only
(D) welds with poor surface appearances

6. In inspection by attributes, the welding inspector is most likely to use a:

(A) radiograph to determine size of an imperfection
(B) Go No-Go gage to check dimensions of a weld
(C) voltmeter to set the voltage for a variety of welds
(D) variable-voltage power supply during eddy-current testing

7. Weld filler metals are covered in what document?

(A) AWS A5.XX
(B) ASTM Standards
(C) ASME Code, Section XI
(D) Mil Std 27-B

8. To be effective, an inspector will:

(A) promptly correct a welder who is making poor welds
(B) keep his distance from the welding foreman
(C) ensure cooperation by incurring obligation through his decisions
(D) not be stubborn or readily swayed by persuasive arguments

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9. Who is responsible for determining the repair method for a rejected weld?

(A) welding inspector
(B) inspector's supervisor
(C) fabricator
(D) code committee

10. Acceptance criteria in inspection by variables is based on:

(A) mechanical tests
(B) size and/or number of imperfections
(C) use of a Go No-Go gage
(D) ability of the welder to repair defects

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AWS

The Metric System, Welding Terms and Symbols

A lesson from WELDING INSPECTION AND QUALITY CONTROL

Course 36
Lesson, Test 2

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Metric Conversion Factors

To convert from	To	Multiply by
in.	mm	25.4
in.	m	25.4×10^{-3}
mil	µm	25.4
µin.	µm	25.4
$in.^2$	m^2	6.45×10^{-4}
$in.^3$	m^3	1.64×10^{-5}
ft.	m	3.048×10^{-1}
$ft.^2$	m^2	9.29×10^{-2}
$ft.^3$	m3	2.831×10^{-2}
oz.	g	2.834×10
lb.	kg	4.536×10^{-1}
Btu	J	1.054×10^{3}
Btu/lb. • °F	J/kg • K	4.18×10^{3}
Btu/ft. • hr • °F	W/m • K	1.730
10 in./in./ °F	10^{-6} mm/mm/°C	1.8
psi	Pa	6.895×10^{3}
psi	kPa	6.895
ksi	kPa	6.895×10^{3}
ksi	MPa	6.895
ksi • $in.^{½}$	MPa • $m^{½}$	1.099
ksi√in.	MPa • √m	1.099
oz.f	gf	28.4
lbf	kgf	4.536×10^{-1}
lbf	N	4.448
lbf • ft.	N • m (or J)	1.356
$lbf/in.^2$	kgf/cm^2	14.223
$lbf/in.^3$	kgf/m^3	2.768×10^{4}
$lb./ft.^3$	kg/m^3	16.019
$lb./in.^3$	g/cm^3	2.768×10
$lb./in.^3$	kg/m^3	2.768×10^{4}
gal (U.S. liquid)	L	3.785
gal (U.S. liquid)	m^3	3.785×10^{-3}
lb./gal	g/L	119.826
ft./gal	ml/L	748
°F	°C	(°F – 32)/1.8
°F	K	(°F + 459.67)/1.8
°C	°F	(°C • 1.8) + 32
°C	K	°C + 273.15
K	°C	°C – 273.15

Multiple and Submultiple Units

10^{12}	tera	10^{-1}	deci
10^{9}	giga	10^{-2}	centi
10^{6}	mega	10^{-3}	milli
10^{3}	kilo	10^{-6}	micro
10^{2}	hecto	10^{-9}	nano
10	deka	10^{-12}	pico

Abbreviations

J	joule	M	meter	Pa	pascal
kgf	kilogram force	mm	millimeter	K	kelvin
L	liter	N	Newton	W	watt

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The Metric System, Welding Terms and Symbols

Metric measurement is now an important facet of welding inspection. The use of metric units as a replacement for U.S. customary units by American industry is accelerating. Welding inspectors may use U.S. units on one job and metric units on another. The marketplace for fabricated equipment, and other items, is now worldwide, and almost every other country besides the USA uses the Metric System. World-wide competition for our goods and services requires a working knowledge of the Metric System. The Metric System is actually quite simple compared to our English System, and is easily learned with a few hours of study and practice in converting from our English System to Metric, and vice versa.

Upon completion of this lesson the student will be able to:

- Understand the SI International System of Units as related to welding;
- Convert U.S. units to Metric units and vice versa;
- Become familiar with welding terms and their definitions;
- Recognize the various types of fusion and solid state welding processes as well as allied processes such as soldering, brazing and cutting; and
- Become familiar with the eight elements of welding symbols, how these are constructed relative to desired weld and utilized on shop drawings.

SI International System of Units. The official metric system in the United States is the International System of Units, known as "SI" over most of the world. The American Welding Society has published a Metric Practice Guide which will assist the welding industry in converting to SI units. Terms selected for welding use were chosen by AWS in cooperation with national and international organizations.

Basic Units. The SI consists of seven base units and two supplementary geometric units to measure angles. These units and their symbols are listed in Table 1.

A brief description of each metric base and supplementary unit listed in Table 1 is noted below, followed by the National Bureau of Standards definition.

The **meter** is the standard unit of length and is equal to approximately 3.28 feet. The meter's actual length is equal to 1,650,763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $2P_{10}$ and $5d_5$ of the krypton-86 atom. 1 ft. = 0.3048 m.

The **gram** is the standard unit of mass (or weight, in common terms). There are approximately 454 grams in the English pound; mass is more readily referred to using kilograms, which is 1,000 grams. One kilogram is approximately equal to 2.2 lbs. The kilogram is actually equal to the mass of the international prototype of the kilogram. 1 lb. = 0.4536 kg.

Table 1. Base and supplementary SI units

Quantity	SI unit	Symbol
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
luminous intensity	candela	cd
amount of substance	mole	mol
plane angle	radian	rad
solid angle	steradian	sr

Throughout this course, the words *he* and *his* are used as neutral pronouns. This usage is certainly not intended to disregard the many women who contribute to the field of materials science.

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The *second* is the standard unit of time and is the same for both the Metric and English systems. The actual duration of the second is equal to 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.

The **ampere** is the standard unit of current flow and is the same for both the English and Metric systems. The actual quantity of the one ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible cross section, and placed one metre apart in a vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.

The **kelvin** scale for temperature measurement uses a different starting point, or zero point than our more familiar fahrenheit (F) scale. The F scale has a starting point of 32 for the freezing point of water, and a figure of 212 for the boiling point of water. The kelvin scale starts at 0 denoting the temperature at which all atomic movement ceases. A third scale often used is the celsius (C) scale which assigns 0 to the freezing point of water and 100 to water's boiling point. A simple approximate conversion from the F scale to the kelvin scale is to subtract 32 from the F scale temperature, divide by two, and then add 273 to the result. The actual kelvin thermodynamic temperature is equal to 1/273.16 of the thermodynamic temperature of the triple point of water. K = °C + 273; °C = 0.555 (°F-32).

The measure of brightness, or light intensity, is the **candela**. It is equal to the luminous intensity, in the perpendicular direction, of a surface of 1/600,000 metre squared of a blackbody at the temperature of freezing platinum under a pressure of 101,325 newtons per metre squared.

The **mole** is the measure of the amount of a substance based on its atomic makeup; this term is seldom used in the course of welding inspection. The mole is defined as the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kg of carbon-12 (when the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles).

The **radian** is the unit used to measure plane angles; for example, our common 45 angle is about 0.78 radians. A 90 angle is about 1.57 radians. The radian is exactly equal to the plane angle between two radii of a circle that cut off on the circumference an arc equal in length to the radius. Symbol: rad. 1 deg = 0.01745 rad.

The **steradian** is the unit used to measure an angular volume, or solid angle. This unit is also seldom used in welding inspection, but it is exactly equal to the solid angle which, having its vertex in the center of a sphere, cuts off an area of the surface of a sphere equal to that of a square with sides of length equal to the radius of the sphere. Symbol: sr.

There are other units of measure that are used with SI units. Although these units are not strictly SI, they are related to SI as shown in Table 2.

Prefixes for Powers of 10. The metric system is simplified by using powers of ten, 1/1000, 1/100, 1/10, 10, 100, 1,000, as prefixes for the base units. While our English foot is divided by 12, and our mile by 5,280 ft., the metric meter is only divided by, or multiplied by powers of ten to denote all metric lengths. A kilometer is 1,000 m; a centimeter is 1/100 of a meter. Learning a few prefixes, and their corresponding power of ten is simple, and these same prefixes are then applied to all base units of the metric system. Common examples are kilometer, kilogram, etc.

Another convenient system for using large numbers is the use of scientific notation, which denotes

Table 2. Other units used with the SI system

Unit	Symbol	Value in SI units
minute	min	1 min = 60 s
hour	h	1 h = 60 min = 3600 s
day	d	1 d = 24 h = 86,400 s
degree (angular)	°	1° = (π/180) rad = 0.0175 rad
bar	bar	1 bar = 0.1 MPa = 10^5Pa
litre	L(a)	1 litre = 0.001 m^3
degree Celsius	°C	1°C = 1 K (interval)
angstrom	Å	1 Å = 0.1 nm = 10^{-10} m
atmosphere	atm	1 atm = 101,325 Pa

(a) The lower case symbol "l" for litre is easily confused with the digit "1". It has been recommended that the abbreviation be a capital L. To avoid all confusion, spell out the word litre.

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Table 3. Prefex and Symbol for Large and Small Numbers

Number	Exponential Expression	Prefix	Symbol
1,000,000,000,000	10^{12}	tera	T
1,000,000,000	10^{9}	giga	G
1,000,000	10^{6}	mega	M
1,000	10^{3}	kilo	k
0.001	10^{-3}	milli	m
0.000,001	10^{-6}	micro	μ
0.000,000,001	10^{-9}	nano	n

the powers of ten by using exponents. Ten is equal to 10^1, 100 is equal to 10^2, 1,000 is equal to 10^3. Negative exponents denote numbers less than one; 1/10 equals 10^{-1}, 1/100 is equal to 10^{-2}, and 1/1,000 equals 10^{-3}. Another way to consider negative exponents is to remember that it means the number is a reciprocal, that is 1/number.

The decimal notation is simplified by seven preferred prefixes (see Table 3) used to indicate order of magnitude, thus simplifying numeric notation; for example, kilo means 1000, and milli means one-thousandth. The prefixes are a convenient substitute for writing powers of ten in exponential fashion. As a welding example, 45,400 grams (100 lb.) of welding electrodes, which may also be written as 45.4×10^3 grams, is converted by the prefix "kilo" to become 45.4 kilograms (abbreviated 45.4 kg).

As another example, a tensile strength of 100,000 psi is 689,000,000 pascals, which is 689×10^6 pascals (written 689×10^6 Pa), or more simply 689 megapascals (written 689 MPa).

A root spacing for brazing that is 0.0001 metres wide (0.004 in.) is 100 micrometres, written 100 m, to avoid the decimal point followed by so many zeros. Root spacing for a groove weld that might be 1/8 in. in U.S. units, or 0.0032 metres, is 3.2 mm in SI.

Spelling SI Units of Measure. The American Society for Testing and Materials (ASTM) has adopted *litre* and *metre* as the proper spelling for these two units of measure.

The spelling is derived from the European origin of SI. Many U.S. authorities prefer the traditional spelling *liter* and *meter*, and until the question is settled, the welding inspector is likely to encounter both spellings in drawings and documents. The word metre distinguishes between length and the hand tools of the inspector and machinist, known as micrometers.

Summary of SI Units

In SI, there is only one unit for each physical quantity, such as force, energy or power, and these units do not change regardless of whether the process is mechanical, electrical or thermal.

In the U.S. system, force is measured by the dyne, poundal, kip, pound force or ounce force, but in SI it is measured only in newtons. Energy, whether thermochemical heat, mechanical work, kinetic impact or electrical watt-hours and watt-seconds, is measured exclusively in joules. Power, whether in a welding machine or an air conditioner, is measured in watts. By contrast, the U.S. system has nine commonly used units for area, 25 units for energy and 26 units for length.

The International System has an absolute base, free from the action of gravity. This becomes more important to the engineer than to the welding inspector, but it explains why SI is the accepted International System. In SI units, a force of one newton (N) gives a mass of one kilogram (kg) an acceleration of one metre per second squared (1 N = 1 kg m/s^2). In the former European metric practice (a gravitational system), one kilogram force accelerates the same mass (1 kg) 9.806560 metres per second squared.

In U.S. units, one pound force accelerates a mass of one slug 32.174 feet per second squared. In the U.S. system, the pound is used to measure both force and mass. However, we should be using the poundal for force when the pound is used for mass, or the pound for force when the slug is used for mass.

In U.S. units, a force of one poundal applied through a distance of one foot does work equivalent to 0.001284 Btu, which also equals the work produced by one horsepower in 0.00606 hours. However, in the Inter-

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Table 4. Metric conversion factors

To convert from	To	Multiply by
in.	mm	25.4
in.	m	25.4×10^{-3}
$in.^2$	m^2	6.45×10^{-4}
$in.^3$	m^3	1.64×10^{-5}
ft.	m	0.3048×10^{-1}
$ft.^2$	m^2	9.29×10^{-2}
$ft.^3$	m^3	2.831×10^{-2}
oz.	g	2.834×10^{1}
lb.	kg	4.536×10^{-1}
Btu	J	1.054×10^{3}
$A/in.^2$	A/mm^2	1.55×10^{-3}
lb./h	kg/h	0.454
lb. (force)	N	4.448
ft.-lb. (force)	J	1.356
W·h	J	3.6×10^{3}
J/in.	J/m	39.37
$W/in.^2$	W/m^2	1.55×10^{3}
psi	Pa	6.895×10^{3}
N/mm^2	Pa	1×10^{6}
torr	Pa	1.33×10^{2}
in./min	mm/s	0.423
°F	°C	0.555(°F–32)
gal (U.S. liquid)	L	3.785
gal (U.S. liquid)	m^3	3.785×10^{-3}

Abbreviations

A	ampere	l	litre	N	Newton
J	Joule	m	metre	Pa	pascal
kg	kilogram	mm	millimetre	W	watt

national System, a force of one newton applied through a distance of one metre does work equivalent to one joule, which also equals the work produced by one watt of power in one second.

Conversion units from U.S. units to metric units are listed in Table 4. Conversion from one unit to the other normally is done by engineers writing the specifications or making the drawings for a weldment, and the inspector generally need not convert from one system to the other.

Welding Terms and Definitions

Standard terminology is formulated and defined in the publication "Welding Terms and Definitions" (ANSI/AWS A3.0). These preferred terms and definitions should be used in codes, specifications, procedures and all other documents concerning welding. A selection of terms commonly used by the welding inspector is included in this lesson.

Key Definitions. AWS partially defines a weld as, "a coalescence, growing together or growth into one body". When welding metals, a metallic bond is formed as the weld is being made. The forces that hold materials together when welded, brazed, soldered or adhesive bonded are complex. A complete list of types of bonding forces, and their definitions, will be found in A3.0 (for example, adhesive bond, bonding force, covalent bond, ionic bond, metallic bond, permanent dipole bond or van der Waals bond).

The AWS definition of a weld, a braze and braze welding are as follows:

Weld. A localized coalescence of metal or nonmetals produced either by heating the materials to the welding temperature, with or without the application of pressure, or by the application of pressure alone and with or without the use of filler metal.

Braze. A weld produced by heating an assembly to the brazing temperature using a filler metal having a liquidus above 450 °C (840 °F) and below the solidus of the base metal. The filler metal is distributed between the closely fitted faying surfaces of the joint by capillary action.

Braze welding (BW). A welding process that uses a filler metal with a liquidus above 450 °C (840 °F) and below the solidus of the base metal. The base metal is not melted. Unlike brazing, in braze welding the filler metal is not distributed in the joint by capillary action. See also **flow welding.**

Often misunderstood are the terms fusion and penetration. (The preferred term is "joint penetration"). The distinction between them is:

Fusion. The melting together of filler metal and base metal, or of base metal only to produce a weld.

Joint penetration. The distance the weld metal of a weld extends from the weld face into a joint, exclusive of weld reinforcement.

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There are several terms related to the throat and size of a fillet weld:

Theoretical throat. The distance from the beginning of the joint root perpendicular to the hypotenuse of the largest right triangle that can be inscribed within the cross section of a fillet weld. This dimension is based on the assumption that the root opening is equal to zero.

Fillet weld size. For equal leg fillet welds, the leg lengths of the largest isosceles right triangle which can be inscribed within the fillet weld cross section. For unequal leg fillet welds, the leg lengths of the largest right triangle that can he inscribed within the fillet weld cross section.

A fillet weld also has an actual throat and an effective throat:

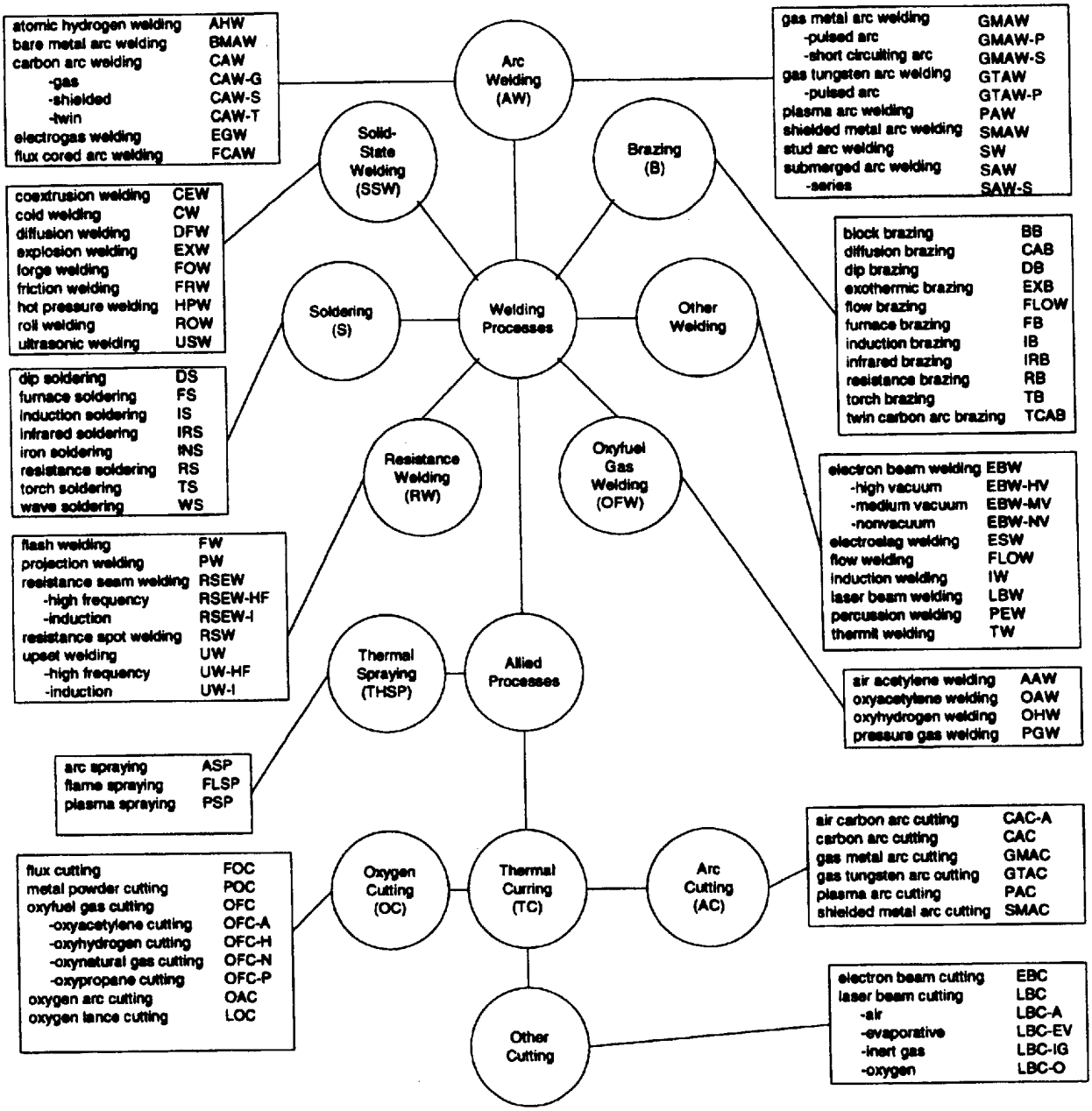


Figure 1. Master chart of welding and allied process. (ANSI/AWS A3.0)

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Actual throat. *The shortest* distance between the weld root and the face of a fillet weld.

Effective throat. The minimum distance minus any convexity between the weld root and the face of the fillet weld.

The American Welding Society considers the terms welder and welding operator applicable to the individual only, and the machine performing the welding operation should be referred to as the welding machine. The equipment that supplies current for electric welding should be referred to as either welding generator or welding transformer. Similar principles apply to the thermal cutting processes.

Welder. One who performs a manual or semiautomatic welding operation.

Welding operator. One who operates adaptive control, automatic, mechanized, or robotic welding equipment.

Welding machine. Equipment used to perform the welding operation. For example, spot welding machine, arc welding machine or seam welding machine.

Welding and Allied Processes

Although an inspector must understand the welding processes that are within the scope of his work, it would be difficult for him to be knowledgeable of all the welding processes. The number of processes in commercial use is large, varied and still growing.

However, the inspector should be familiar with the major processes, know their relationship to each other and their areas of application. The welding processes are listed in Figure 1, and those most commonly used are discussed in Lesson 5.

Welding Positions

The usual welding positions are flat, horizontal, vertical and overhead, as shown for groove and fillet welds in Figure 2. In some welding, the positions of the hours on a clock are used as reference locations.

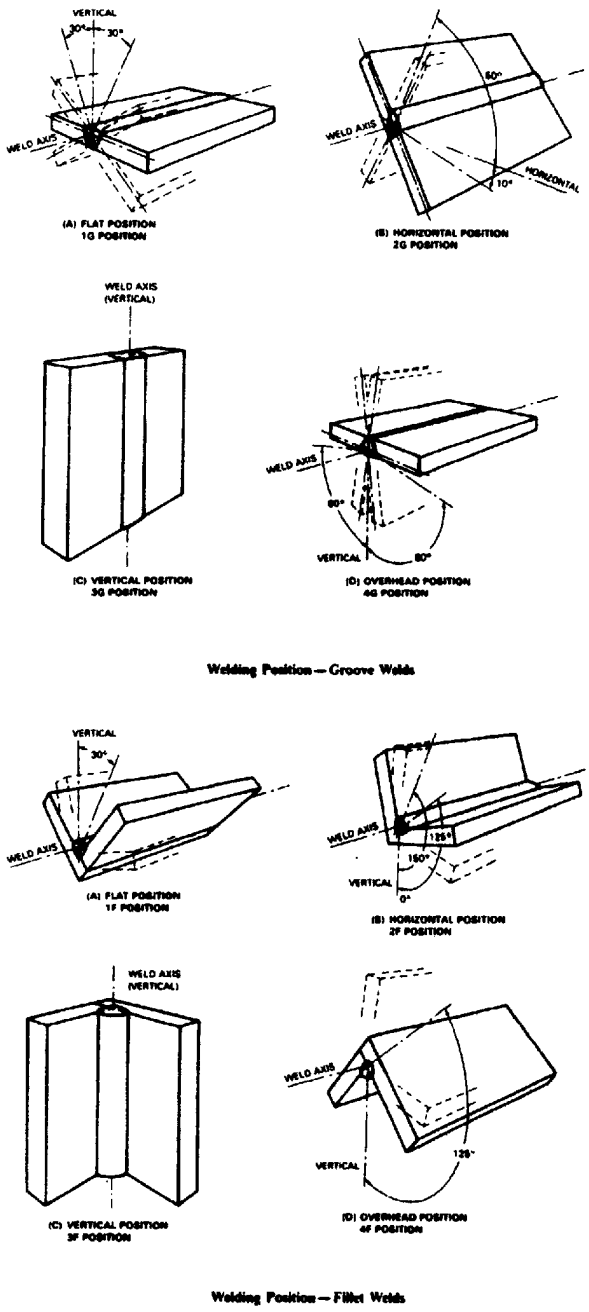
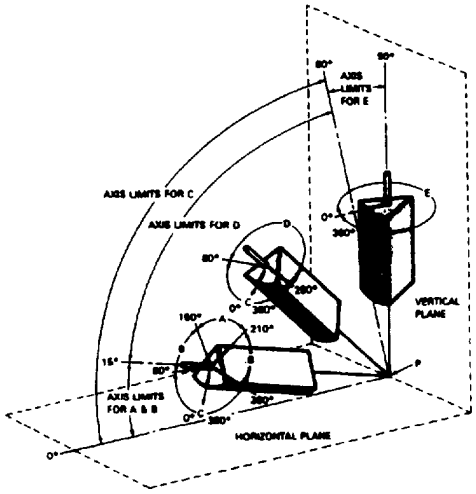


Figure 2. Welding positions: (top) groove welds; and (bottom) fillet welds.

The flat position is the easiest for welding. In this position, welding benefits from the force of gravity, because gravity helps keep the molten weld pool in place, and maximum deposition rates are obtained. Next in ease of welding is the horizontal

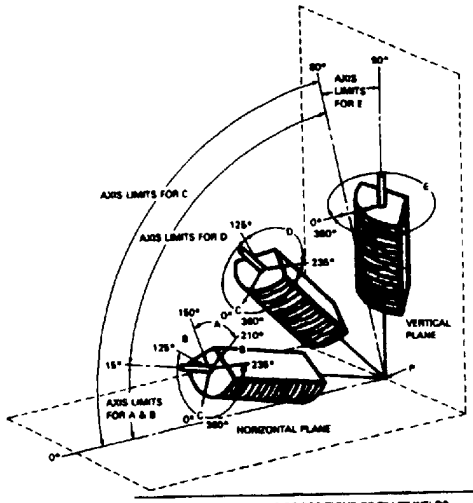
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a)

TABULATION OF POSITIONS OF GROOVE WELDS

POSITION	DIAGRAM REFERENCE	INCLINATION OF AXIS	ROTATION OF FACE
FLAT	A	0° to 15°	150° to 210°
HORIZONTAL	B	0° to 15°	80° to 150° 210° to 280°
OVERHEAD	C	0° to 80°	0° to 80° 280° to 360°
VERTICAL	D E	15° to 80° 80° to 90°	80° to 280° 0° to 360°



b)

TABULATIONS OF POSITIONS OF FILLET WELDS

POSITION	DIAGRAM REFERENCE	INCLINATION OF AXIS	ROTATION OF FACE
FLAT	A	0° to 15°	150° to 210°
HORIZONTAL	B	0° to 15°	125° to 150° 210° to 238°
OVERHEAD	C	0° to 80°	0° to 125° 238° to 360°
VERTICAL	D E	15° to 80° 80° to 90°	125° to 238° 0° to 360°

Notes:
1. The horizontal references plane is always taken to lie below the weld under consideration.
2. The inclination of the weld axis is measured from the horizontal reference plane toward the vertical reference plane.
3. The angle of rotation of the weld face is determined by a line perpendicular to the weld face at its center which passes through the weld axis. The reference position (0°) of rotation of the weld face invariably points in the direction opposite to that in which the weld axis angle increases. When looking at point P, the angle of rotation of the weld face is measured in a clockwise direction from the reference position (0°).

Figure 3. Welding position diagram for: (a) groove welds in plate, and (b) fillet welds in plate.

fillet position, in which the force of gravity helps to some extent. For welding in these positions, the joint should be level, or nearly so, when possible.

Welding in positions other than flat (frequently referred to as out-of-position welding) requires the use of manipulative techniques and electrodes that result in faster freezing of the molten metal and slag, to counteract the effect of gravity.

The angular variations for the various welding positions are given in Figure 3. Some general conditions that determine the position of welds are as follows:

1. The horizontal reference plane is taken to lie below the weld under consideration.

2. Inclination of axis is measured from the horizontal reference plane toward the vertical plane.

3. Angle of rotation of face is determined by a line perpendicular to the theoretical face of the weld, and which passes through the axis of the weld. The reference position (zero rotation) of the face invariably points in the direction opposite to that in which the axis angle increases. The angle of rotation of the face of a weld is measured in a clockwise direction from this reference position (zero rotation) when looking at point P (see Figure 3).

For groove welds in pipe, see Figure 4.

Standard Welding Symbols

Welding cannot take place as an engineering tool unless means are provided for conveying the information from the designer to the welder. Such practices as writing "to be welded throughout" or "to be welded completely" on a drawing, erroneously trans-

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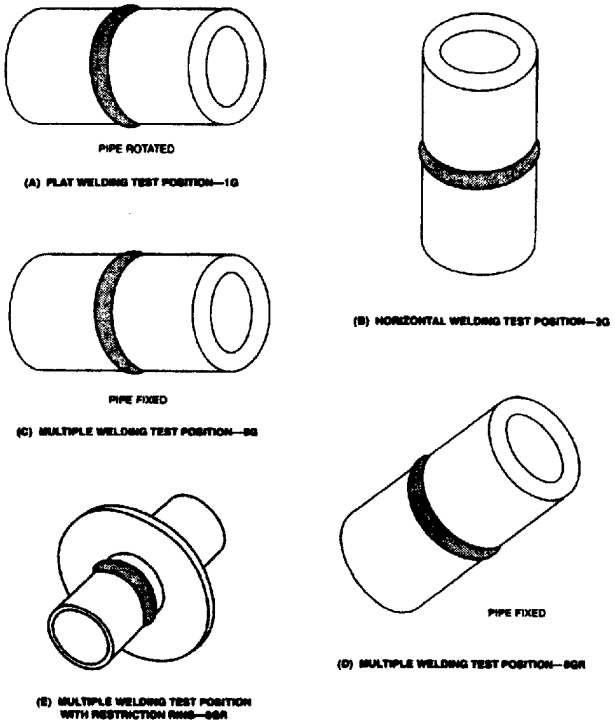


Figure 4. Welding test positions and their designations for groove welds in pipe.

fer the design of all attachments and connections from the designer to the welder, who cannot be expected to know what strength is necessary.

Welding symbols provide the means of placing complete welding information on the engineering drawings. In practice, many companies may only need a few of the symbols, and can select only those that fit their needs.

The use of the words "far side" and "near side" in the past has caused confusion, because when joints are shown in section, all welds are equally distant from the reader. In the present system, the joint is the basis of reference. Any joint that is indicated by a welding symbol will always have an "arrow side" and an "other side". Accordingly, the words "arrow side", "other side" and "both sides" are used in the present system to locate the weld with respect to the joint.

This course deals principally with arc welding; therefore, sections referring to resistance welding, brazing and other processes have been omitted. To assist the student in acquiring competence in the use of the more commonly used symbols, only fillet welds, square, Vee, bevel, U and J groove welds and backing welds are covered in detail. However, the student should be aware of the breadth and completeness of the American Welding Society's system and should obtain a copy of the current edition of AWS A2.4. After mastering the essentials, the student should memorize other rules that may apply to the welding work on which he is engaged.

Elements of Welding Symbols

The standard welding symbols formulated by the American Welding Society are graphic assemblies of the following eight elements, or those elements that are necessary.

1. Reference line
2. Arrow
3. Basic weld symbol
4. Dimensions and other data, as needed
5. Supplementary symbols
6. Finish symbols, as needed
7. Tail
8. References to specifications, processes or other information, as needed.

The elements of a welding symbol have standard locations with respect to each other, as shown in Figure 5.

Reference line. The basis of a welding symbol is the reference line. Most of the welding symbols are placed above, on or below this line, as described in the subsequent paragraphs. Generally, this is a horizontal line; however, for convenience, the line may be at a slight angle but not vertical.

Arrow. The arrow may point up or down and may be at either end of the reference line. The

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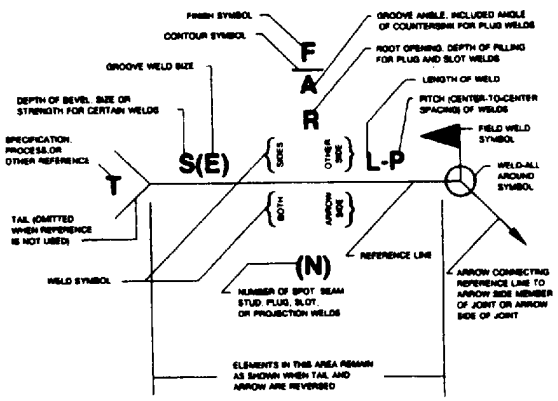


Figure 5. Standard location of elements of a welding symbol.

arrow connects the reference line to the joint to be welded. The side to which the arrow points is called the arrow side of the joint.

Basic weld symbols that indicate the types of welds used to join the members are shown in Figure 6. All arc weld symbols are similar in shape to the cross section of the weld they represent The basic types of joints and applicable welds referred to by these symbols are shown in Figure 7. The

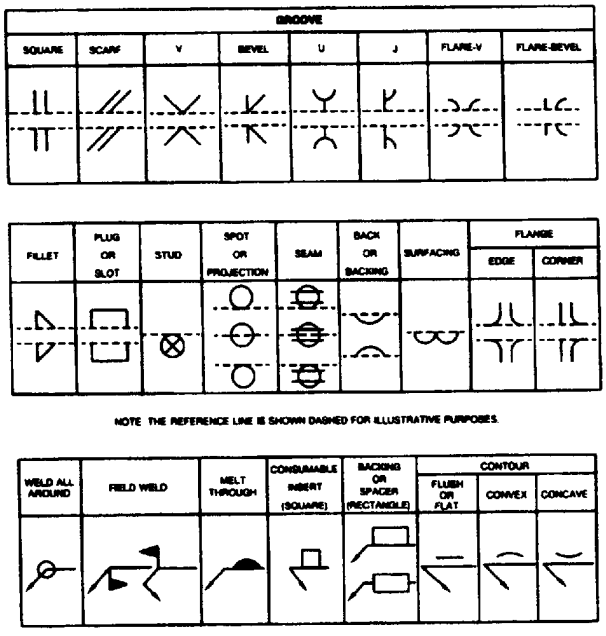


Figure 6. Weld and supplementary symbols.

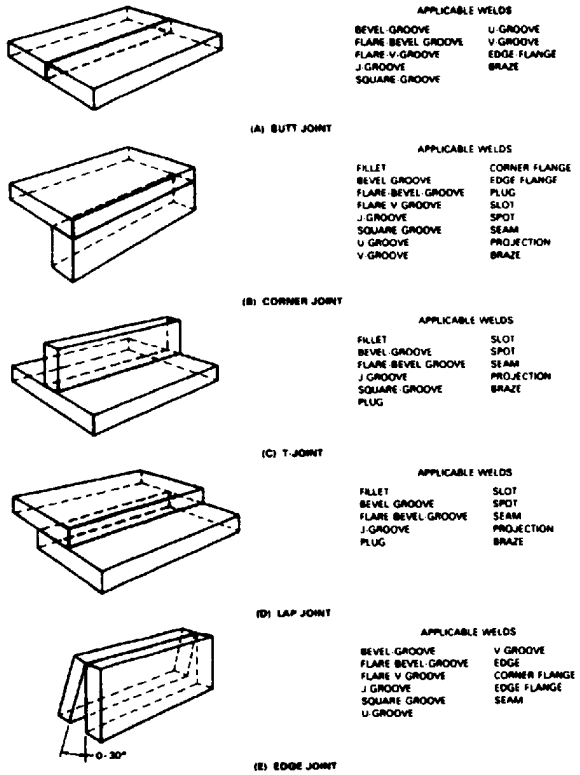


Figure 7. Basic types of joints and applicable welds.

basic groove welds–square, Vee, bevel, U and J–and the plug, spot and surfacing welds are self-descriptive. Flare welds join cylindrical objects to themselves (flare-V) or to flat surfaces (flare bevel), or, to join flanged surfaces to other flanges (flare-V) or to flat surfaces (flare-bevel). These are shown in Figure 8. A fillet weld is an inside corner weld. Spot, projection and seam welds usually are made with resistance welding equipment to create a weld nugget at the interface of the mating pieces. A back weld (made after the opposite side of the joint has been partially or completely welded) and a backing weld (made before the opposite side is welded) are needed to ensure complete joint penetration in certain configurations. The sheet metal flange welds are prepared by bending two or more sheets to make an edge, or one sheet to make a corner.

Dimensions. The length of the leg, length of weld, size and spacing of intermittent welds and similar data are placed above or below the reference line of the weld symbol, adjacent to the welding symbol.

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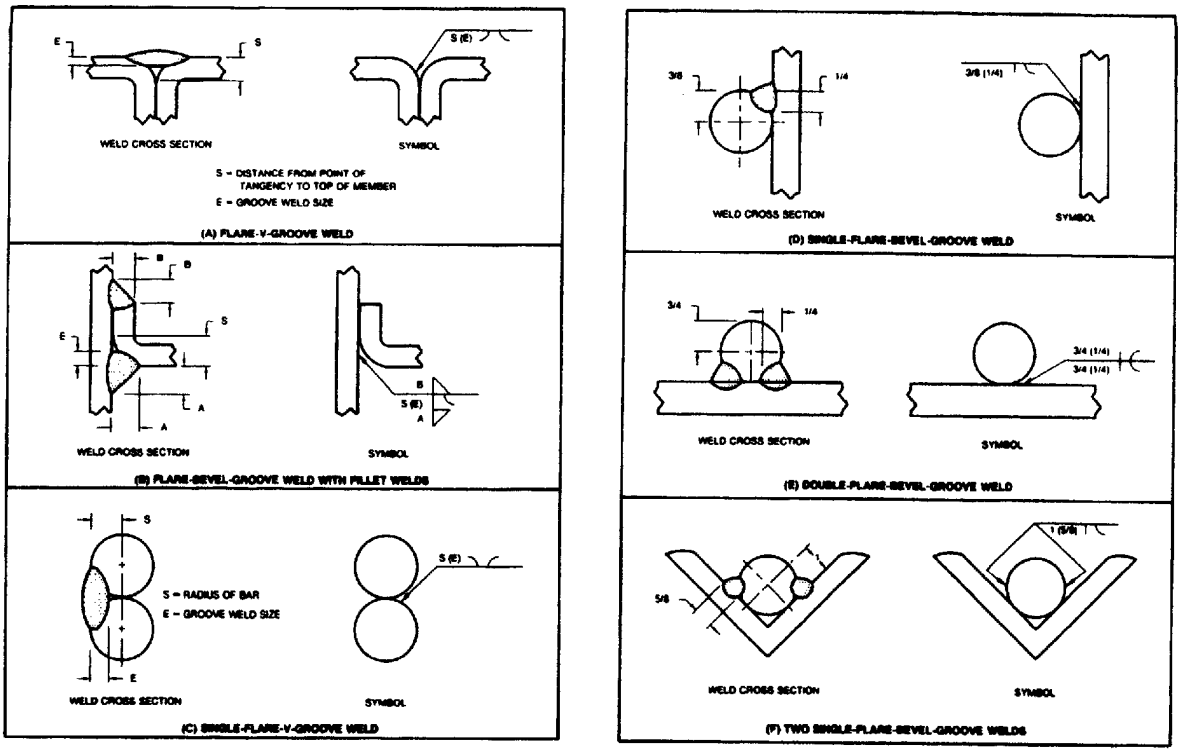


Figure 8. Application of flare-bevel and flare-V-groove weld symbols.

Supplementary symbols, such as shown on the bottom line of Figure 6, are used to provide additional information regarding the weld.

Finish symbols are used to indicate the method of finishing the surface contour of the weld bead.

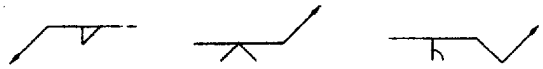
Tail. The tail of the symbol is used for designating the welding specifications, procedures or other supplemental information needed in making the weld. The notation placed in the tail usually is established by each company. If notations are not used, the tail may be omitted.

Specifications or Process References. When it is necessary to record a specification or welding process as part of the weld symbol, it is placed in the tail.

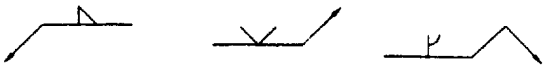
Construction of Welding Symbols

Welding symbols are constructed by drawing a horizontal line, which is the reference line, and connecting it to one side of the joint with an arrow. The arrow is broken to point to whichever face of a bevel or J-groove joint requires preparation.

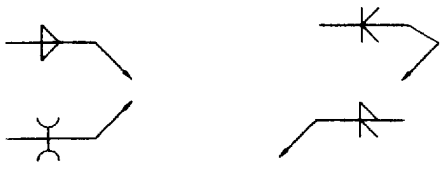
Location of Weld Symbol. Welds on the arrow side of the joint are shown by placing the weld symbol below the reference line.



Welds on the other side of the joint are shown by placing the weld symbol above the reference line.

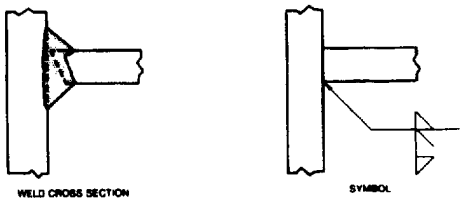


Welds on both sides of the joint are shown by placing weld symbols both below and above the reference line directly opposite each other.

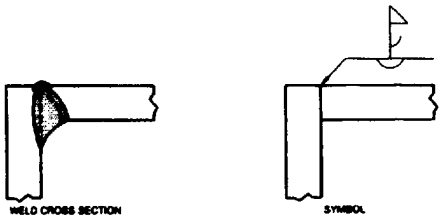


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There is one characteristic of welding symbols that will simplify reading engineering drawings. It is the location of the reference line with respect to the joint in a horizontal plate, or a vertical joint viewed in cross section. When the welding symbol is placed on the drawing below the joint, the groove preparation will be oriented the same as the symbols on the reference line, as shown in the following.



When the symbol is placed on the drawings above the joint, the symbols are inverted from the desired position of the welds in and on the joint.



For joints with the groove displayed horizontally such as a circumferential joint in a vertical tank, the arrow side/other side features are left or right, not above or below.

A joint may be shown by two different symbols, as shown in Figure 9. When the welding symbol arrow points to the face of the joint, the weld symbol is placed below the reference line (see column 2). When the arrow points to the root of the joint, the weld symbol is placed above the reference line (see column 3). When the arrow shaft is broken, the arrow points to the face requiring edge preparation (see bottom two rows). The type of weld indicated by the symbol is pictured in column 1.

Location of Other References. When a specification, process or other reference is used with a welding symbol, the reference is placed in the tail. The welding process is indicated by one or more of the letter designations shown in Figure 1.

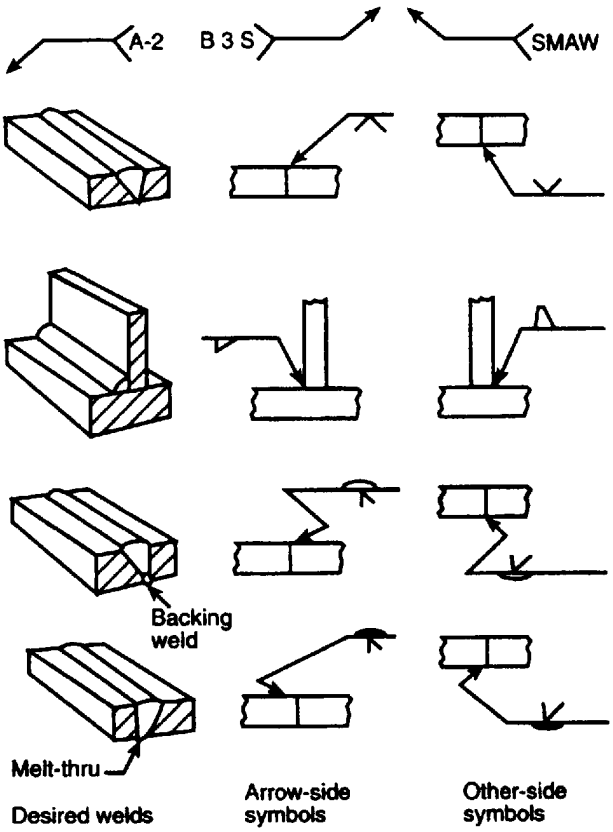


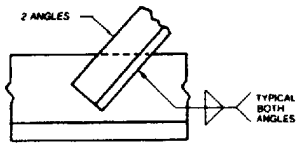
Figure 9. Use of different symbols for the same welds.

When no specification, process or other reference is used with a welding symbol, the tail may be omitted.

General notes may be placed on the drawing to provide detailed information pertaining to the predominating welds, specifications, processes or other references, and this information need not be repeated on the symbols.

Extent of Welding. Unless otherwise indicated, welding symbols denotes continuous welds. Symbols only apply between abrupt changes in the direction of welding, or to the extent of hatching or dimension lines (see Figure 10), except when the weld-all-around symbol is used. When the welding of a hidden member is the same as that of a visible member, it may be specified as shown below. If the welding of a hidden member is different from that of a visible member, specific information for the welding of both should be specified.

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Weld-All-Around Symbol. A continuous weld, whether single or combined type, extending around a series of connected joints may be specified by the addition of the weld-all-around symbol at the junction of the arrow and reference line. The series of joints may involve different directions and may lie in more than one plan (see Figure 11). Welds extending around the circumference of a pipe are excluded from the requirement regarding changes in direction and do not require the weld-all-around symbol to specify a continuous weld.

Field Weld Symbol. Field welds (welds not made in a shop or at the place of initial construction) are indicated by the field weld symbol. The flag is placed at a right angle to, and on either side of, the reference line at the junction with the arrow.

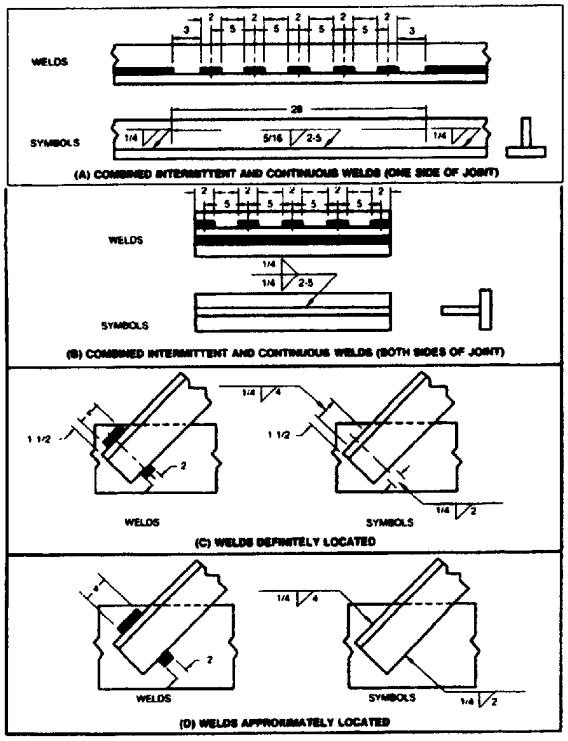
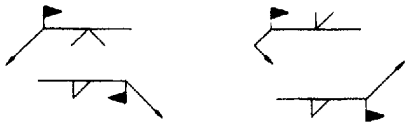


Figure 10. Specification of location and extent of fillet welds: (a) combined intermittent and continuous welds (one side of joint); (b) combined intermittent and continuous welds (both sides of joint); (c) welds definitely located; and (d) welds approximately located.



Finishing welds, other than cleaning, is indicated by the appropriate contour and finish symbols. The following finish symbols indicate the method, not the degree, of finish: C, chipping; G, grinding; H, hammering; M, machining; and R, rolling.

The three contour symbols (shown in Figure 6) indicate whether a flush, convex or concave profile is desired.

Melt-Through Symbol. The melt-through symbol is used only when complete joint penetration plus visible root reinforcement is required in welds made from one side (see Figure 12). The symbol is placed on the side of the reference line opposite the weld symbol. The height of root reinforcement may be specified by placing the required dimension to the left of the melt-through symbol. The height of root reinforcement may be unspecified.

Edge-flange welds requiring complete joint penetration are specified by the edge-flange weld symbol with the melt-through symbol placed on the opposite side of the reference line. Corner-flange welds requiring complete joint penetration are specified by the corner-flange weld symbol with the melt-through symbol placed on the opposite side of the reference line. A broken arrow is pointed to the member to be flanged where the joint does not give this information (Figure 12).

Weld Dimensions On Symbols

The preceding discussion described the weld symbols used on drawings and their placement and meanings. Dimensions must be added to these weld symbols to indicate the sizes of the bevels to be made on the parts to be welded, and the sizes of the fillets, length and pitch of intermittent welds and other information about the welds. This informa-

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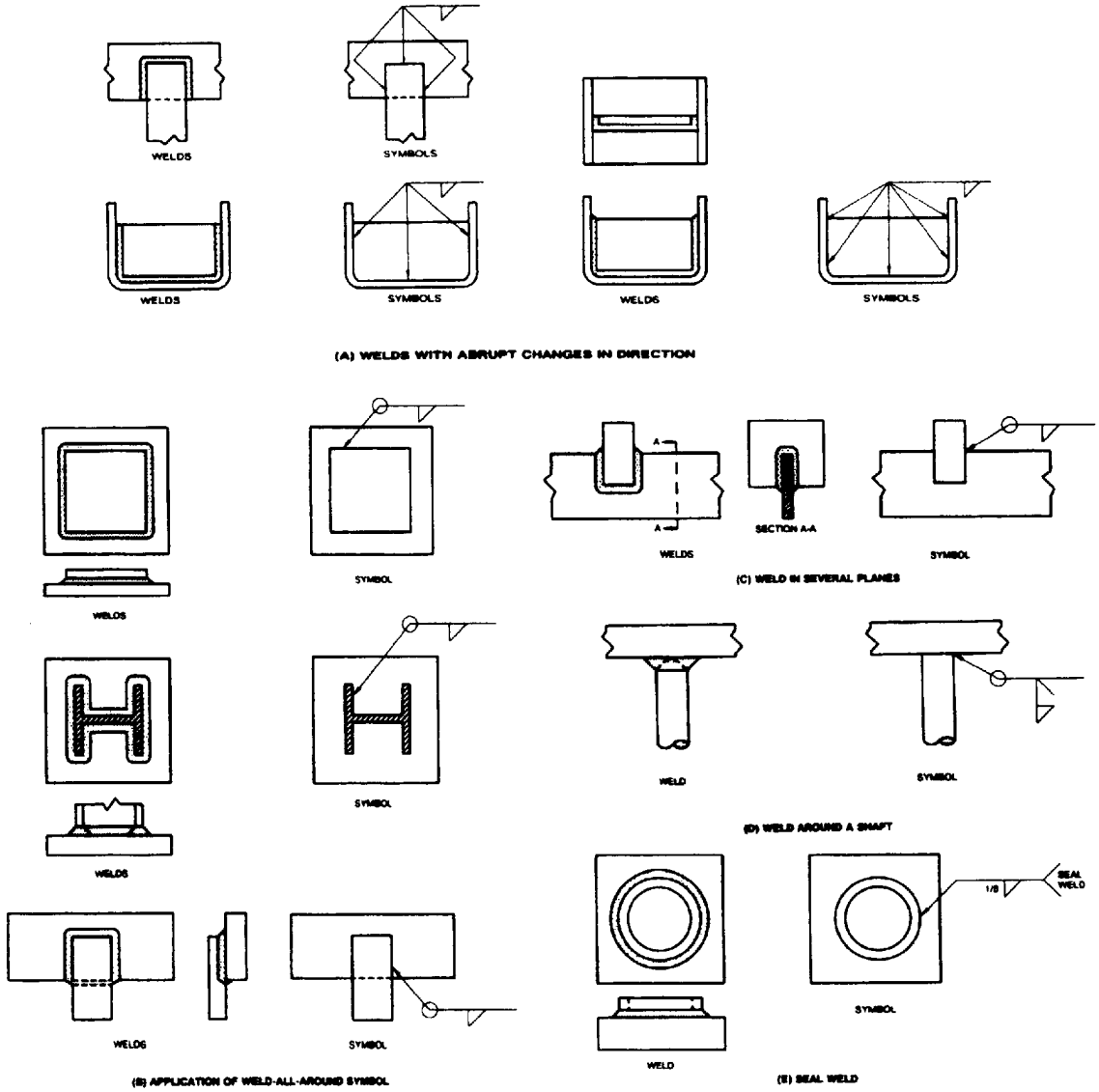


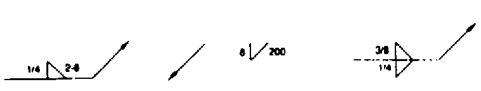
Figure 11. Specification of extent of welding: (a:) welds with abrupt changes in direction; (b) application of weld-all-around symbol; (c) weld in several planes; (d) weld around a shaft; and (e) seal weld.

tion is placed to read from left to right along the reference line, in accordance with the usual drafting practices. The following discussion explains the use of such dimensions.

Fillet Welds. Dimensions of fillet welds are shown on the same side of the reference line as the weld symbol.

The dimensions of fillet welds on both sides of a joint are specified whether the dimensions are identical or different (see Figures 13b and c and Figures 14).

The fillet weld size is specified to the left of the weld symbol (Figure 13).





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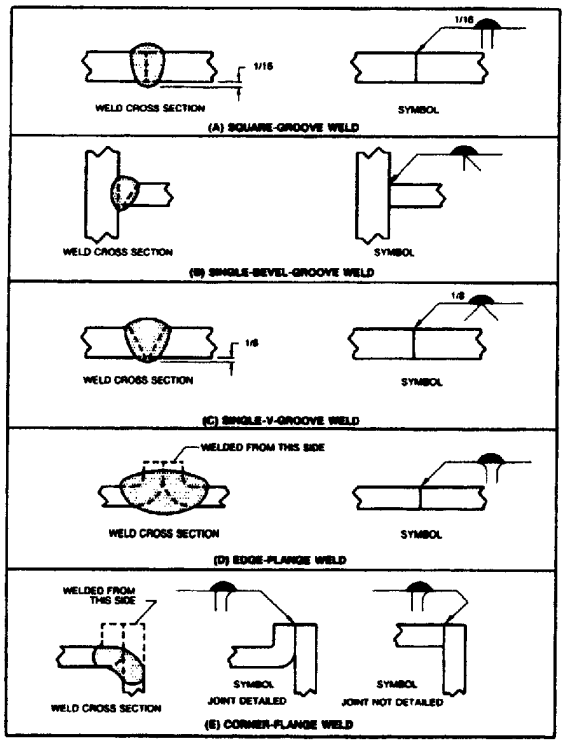


Figure 12. Applications of melt-through symbol: (a) square-groove weld; (b) single-bevel-groove weld; (c) single-V-groove weld; (d) edge-flange weld; and (e) corner-flange weld.

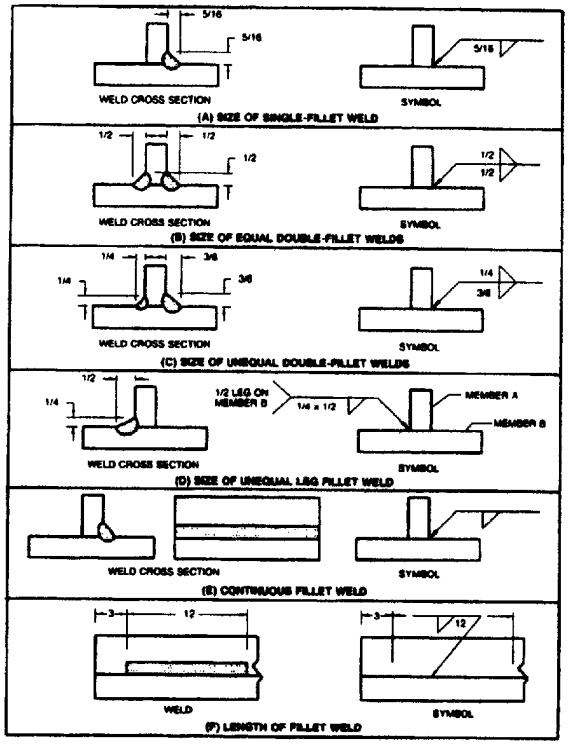
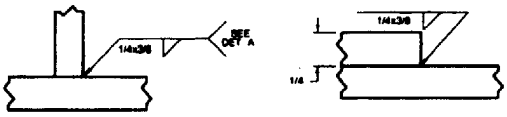
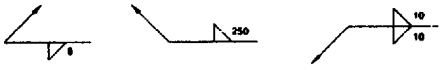


Figure 13. Specification of size and length of fillet welds: (a) size of single-fillet weld; (b) size of equal double-fillet welds; (c) size of unequal double-fillet welds; (e) size of unequal leg fillet weld; (e) continuous fillet weld; and (f) length of fillet weld.

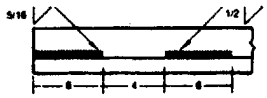
The size of a fillet weld with unequal legs is specified to the left of the weld symbol as shown below.



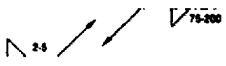
The length of a fillet weld, when indicated on the welding symbol, is specified to the right of the weld symbol (Figure 13f).



When a fillet weld extends for the full length of the joint, no length dimension need be specified on the welding symbol. Specific lengths of fillet welds, and their location, may be specified by symbols in conjunction with dimension lines (Figures 10 and 13). The extent of fillet welds may be specified graphically by hatching.



The pitch of intermittent fillet welds is the distance between centers of increments on one side of the joint, and is shown to the right of the length dimension following a hyphen (see Figure 14).



The application of dimensions to fillet weld symbols and their graphic meaning are illustrated in Figure 13.

Chain intermittent fillet welding and staggered intermittent fillet welding are shown by the length

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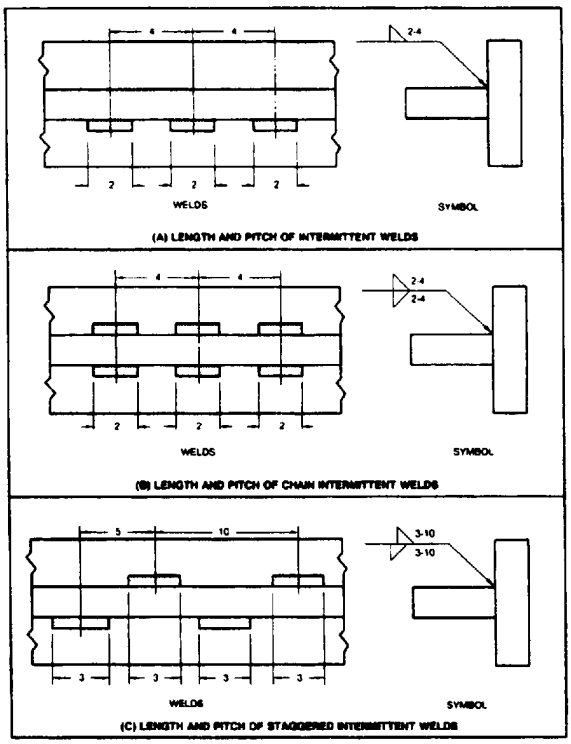
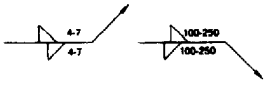


Figure 14. Applications of intermittent fillet weld symbols: (a) length and pitch of intermittent welds; (b) length and pitch of chain intermittent welds; and (c) length and pitch of staggered intermittent welds.

dimension and pitch on both sides of the joint. Chain intermittent fillet welding is shown thus:



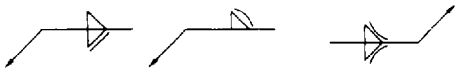
Staggered intermittent fillet welding is shown thus:



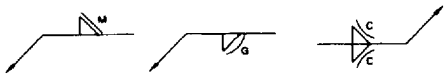
Application of these symbols and the desired welds are shown in Figure 14b and c. These are sequences of welds on opposite sides of the joint. Chain welds are symmetrically located and the staggered pattern is alternating.

Separate welding symbols are used for intermittent and continuous fillet welding when the two are in combination along one side of the joint.

Fillet welds that are to be welded approximately flat, convex or concave faces without postweld finishing are shown by adding the flat, convex, or concave contour symbol to the welding symbol.



Fillet welds that are to be finished approximately flat, convex, or concave by postweld finishing are shown by adding both the appropriate contour and finishing symbols to the welding symbol.

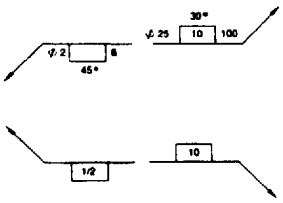


Plug Welds

Plug welds are made by making a circular hole in one member of a joint. The parts are joined by partially or completely filling the hole with weld metal. Laying a fillet weld around the inside of the hole does not meet the requirement.

Holes in the arrow side member of a joint to be plug welded are indicated by placing the weld symbol on the lower side of the reference line. Plug welds in the other side are indicated by a plug weld symbol on the upper side of the reference line. The size or diameter of a plug weld is shown to the left of the plug weld symbol and is preceded by the diameter symbol; the center-to-center spacing (pitch) of plug welds is shown to the right of the symbol. The included angle of countersink, when not the user's standard, is shown below or above the symbol.

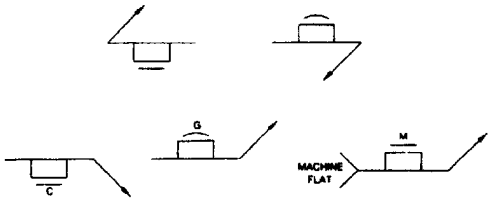
The hole must be completely filled with weld metal unless otherwise indicated. When the depth of filling is less than complete, the depth is given inside the plug weld symbol.



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Plug welds that are to be welded approximately flush or convex faces without postweld finishing are indicated by adding the flush or convex contour symbol to the welding symbol. Welds that are to be made flush or convex by postweld finishing are indicated by both the appropriate contour and finishing symbols to the welding symbols. Welds that require a flat but not flush surface require an explanatory note in the tail of the welding symbol.

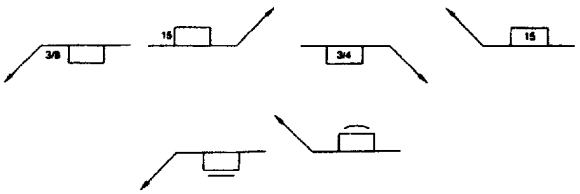


Slot Welds

Joints may be made by machining a slot in one member and welding in the same manner as for plug welds. Slots in a member of a joint to be slot-welded are indicated by placing the slot weld symbol on the appropriate side of the reference line. Again, a fillet weld around the inside of the slot does not fulfill the definition of a slot weld.

Length, width, spacing, included angle of countersink, orientation, and location of slot welds cannot be shown on the welding symbol. These data must be shown on the drawing or by a detail with a reference thereto on the welding symbol. The depth of filling, which must be complete unless otherwise indicated, is shown inside the weld symbol.

Surface finish and contour of slot welds are shown by adding the flush contour symbol and the user's standard finish symbol to the weld symbol.

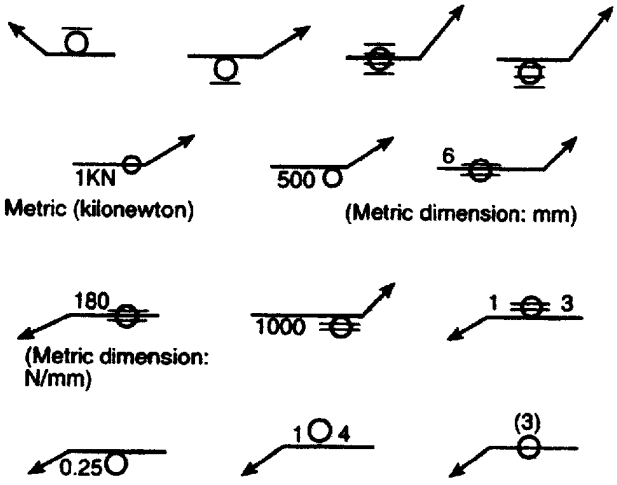


Spot Welds and Seam Welds

The spot weld and seam weld symbols may or may not have arrow side or other side significance.

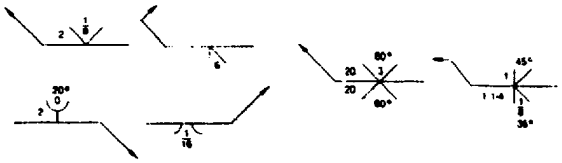
Dimensions are shown on the same side of the reference line as the symbol, or on either side when the symbol is astride the reference line. The spot size (diameter) and tensile strength (in newtons or pounds per spot, or in pounds per linear length of seam), are placed to the left of the weld symbol. The spacing (pitch) is added to the right. The number of spots desired in a certain joint is shown in parentheses either above or below the weld symbol.

When the exposed surface of either member of a spot or seam welded joint is to be flush, that surface is indicated by adding the flush contour symbol to the weld symbol, thus:



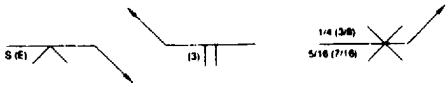
Groove Welds

Dimensions showing preparation of groove welds are indicated on the same side of the reference line as the weld symbol. For double-groove welds both sides of the reference line must be dimensioned.



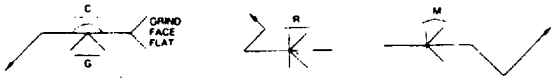
Size and effective throat of groove welds are shown to the left of the weld symbol. Except for square-groove welds, the effective throat *E* in relation to the depth of groove preparation *S* is shown as *S* (E) to the left of the weld symbol. Effective throat only is shown for the square groove weld.

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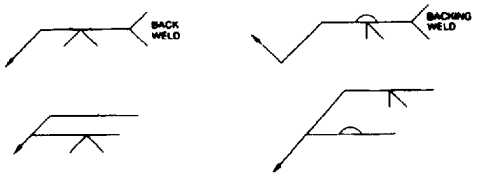


The root opening and groove angle are shown inside the weld symbol.

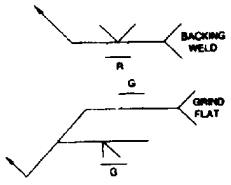
Groove welds that are to be welded or machined flush or convex are shown by adding the contour and machining symbols to the weld symbol.



Back or backing welds of single-groove welds are indicated by placing a back or backing weld symbol on the side of the reference line opposite the groove weld symbol. No dimensions, except height of the reinforcement, are given on the weld symbol. Back or backing welds that are to be welded approximately flush without using a finishing method are shown by adding the flush contour symbol to the back or backing weld symbol.



Back or backing welds that are to be mechanically finished flush or to a convex contour are indicated by adding both the appropriate contour symbol and the user's standard finish symbol to the weld symbol, thus:



Surfacing welds are shown by the surfacing weld symbol, which is always placed below the reference line. The minimum height of weld deposit (if specified) is placed to the left of the weld symbol. Extent, location and orientation of the area to be built up must be shown on the drawing.

Flange Welds

Flange welds are indicated by the edge-flange and corner-flange symbol. The radius and height above the point of tangency, separated by a plus sign, are placed to the left of the weld symbol, reading in that order from left to right along the reference line. The size dimension is added outward of the flange dimensions. The root opening is not placed on the welding symbol. It must appear on the drawing.



Use of the welding symbols, the position and meaning of the elements of the symbols, and the identification of the arrow side and other side of various weld joints are summarized in Figure 15 through 22. Applications of "typical" welding symbols.

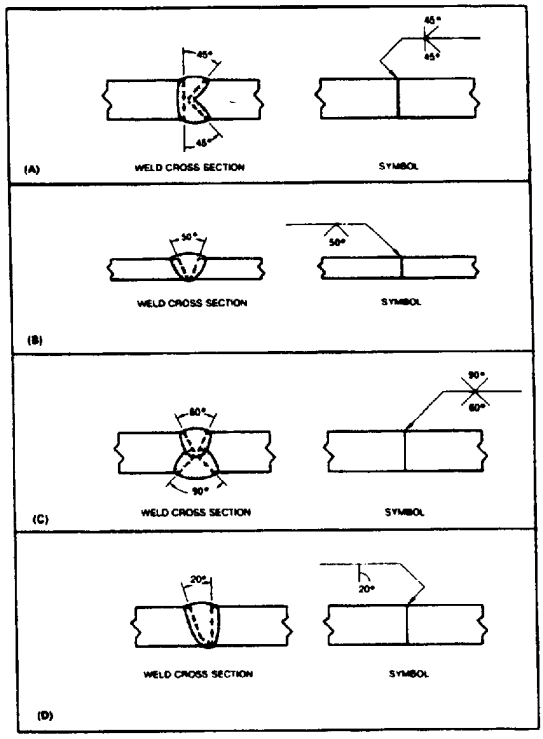


Figure 15. Specification of groove angle of groove welds.

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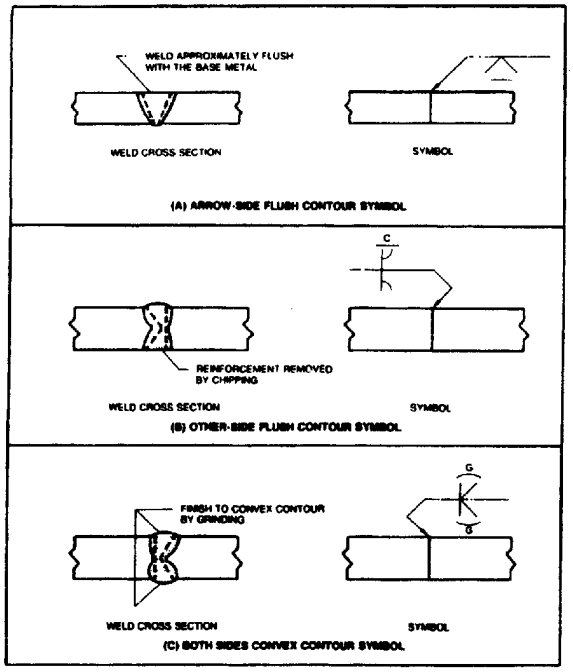


Figure 16. Applications of flush and convex contour symbols: (a) arrow-side flush contour symbol; (b) other-side flush contour symbol; and (c) both sides convex contour symbol.

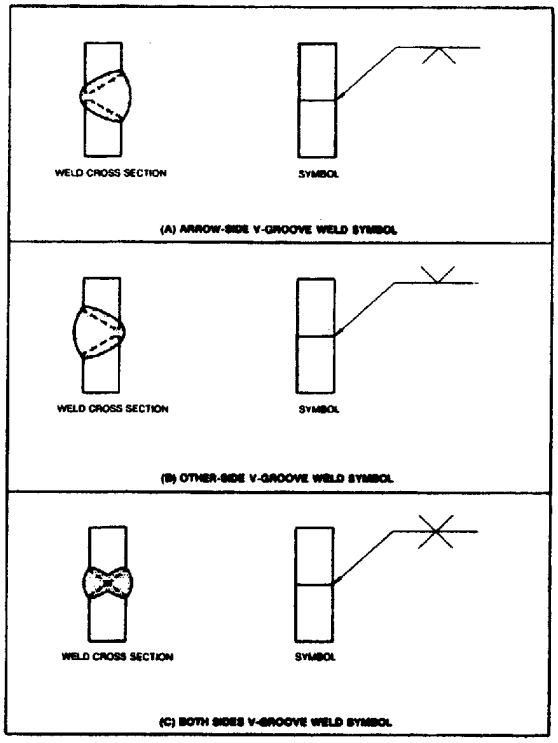


Figure 18. Application of arrow and other side convention.

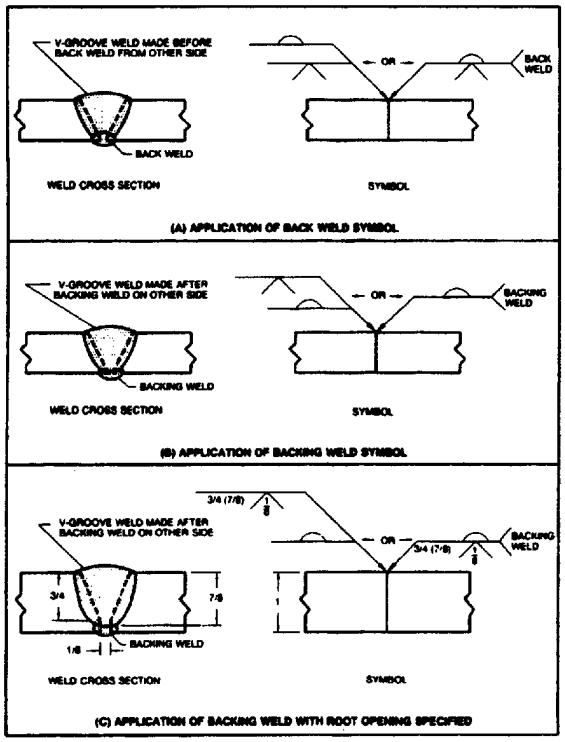


Figure 17. Applications of back or backing weld symbol.

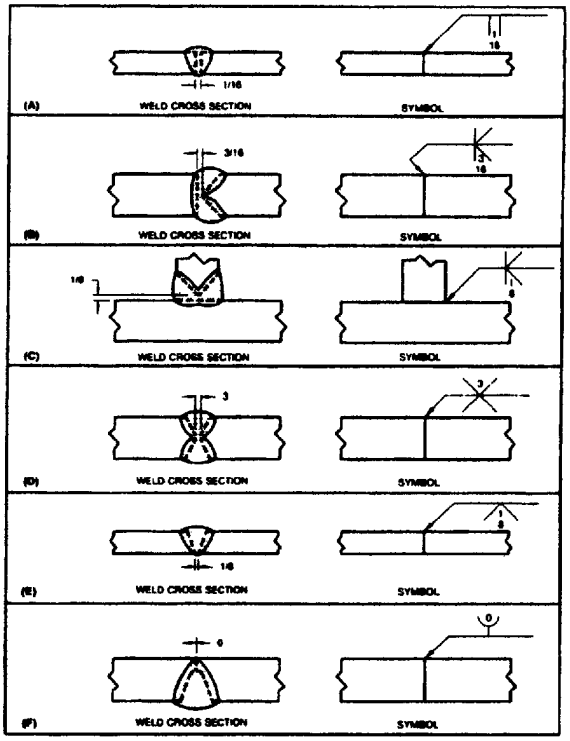


Figure 19. Specification of root opening of groove welds.

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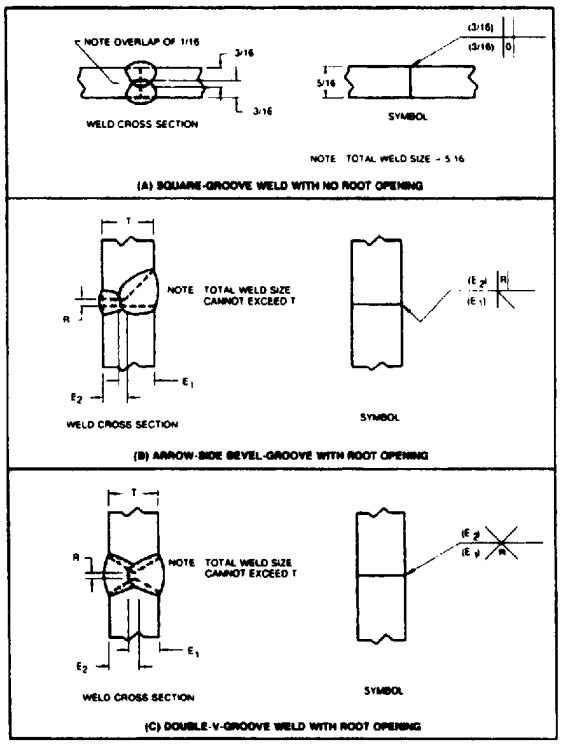


Figure 20. Specification of groove weld size only: (a) square-groove weld with no root opening; (b) arrow-side bevel-groove with root opening; and (c) double-V-groove weld with root opening.

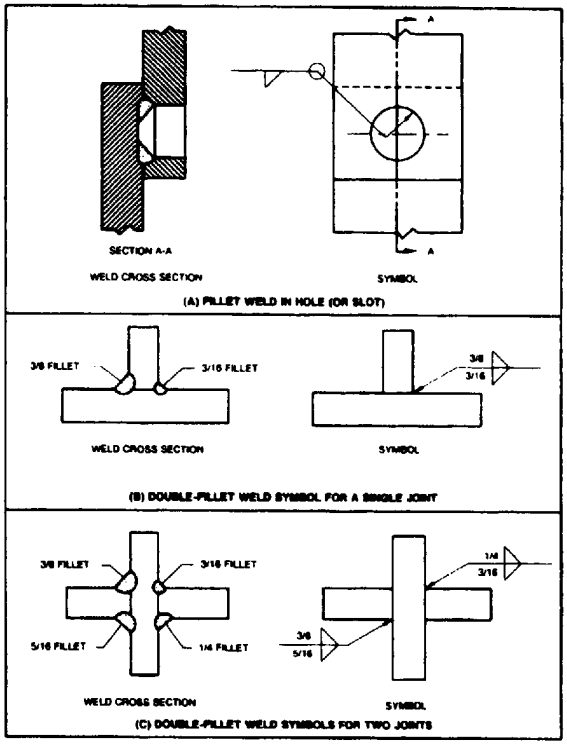


Figure 21. Application of fillet weld symbol; (a) fillet weld in hole (or slot); (b) double-fillet weld symbol for a single joint; and (c) double-fillet weld symbols for two joints

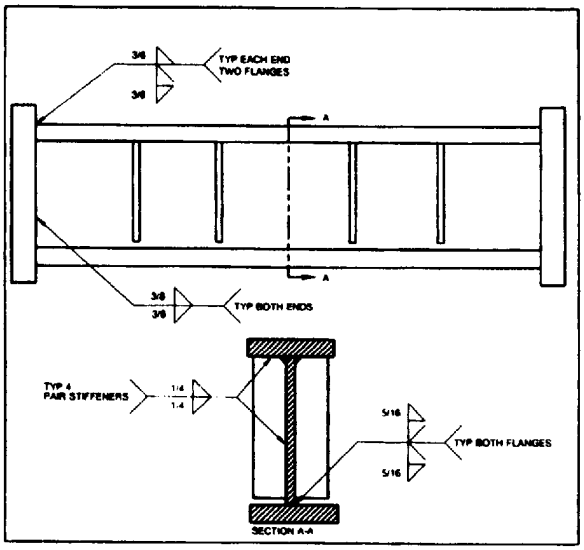


Figure 22. Applications of "typical" welding symbols.

Nondestructive Testing Symbols

ANSI/AWS A2.4 also describes the symbols used for specifying the nondestructive testing requirements for welds. The conventions used are very similar to those used for welding symbols. The abbreviations used on drawings to specify nondestructive examination are given in Table 5.

The testing symbol has the same elements as the welding symbol, namely a reference line, arrow, tail, and arrow side and other side locations. Tests to be made on the arrow side, other side, or both sides of the part are marked on the corresponding sides of the reference line. However, when nondestructive testing symbols have no arrow or other side significance, the testing symbols are centered on the reference line. Nondestructive testing symbols and welding symbols may be combined in

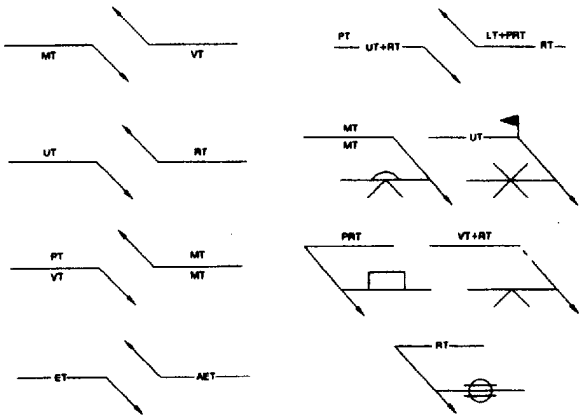
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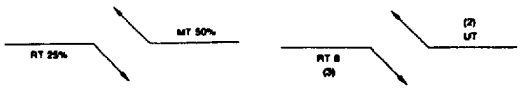
Table 5. Examination method letter designations

Examination Method	Letter Designation
Acoustic emission	AET
Electromagnetic	ET
Leak	LT
Magnetic particle	MT
Neutron radiographic	NRT
Penetrant	PT
Proof	PRT
Radiographic	RT
Ultrasonic	UT
Visual	VT

many ways as shown below. Tests made all around a joint are specified by the test-all-around symbol.

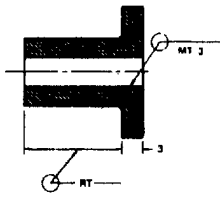


When the full length of a part is to be tested, no length dimension need be shown on the testing symbol. When less than the full length of a weld or part is to be tested, the length or the percentage of the length to be tested is indicated to the right of the basic test symbol. The number of tests to be taken on a joint or part at random locations is shown in parentheses above or below the symbol.

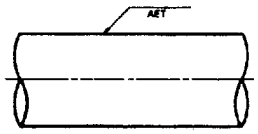


For nondestructive testing areas of revolution, the area is indicated by using the test-all-around symbol and appropriate dimensions.

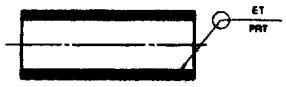
The MT symbol below indicates that the bore of the flange is to be subjected to a magnetic particle examination for a distance of three inches from the face, all the way around. The RT symbol in the same view indicates an area of revolution to be subjected to radiographic examination where dimensions are not available on the drawing.



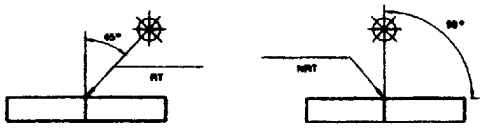
Acoustic emission is generally applied to all or a large portion of a component, such as a pressure vessel or pipe. The symbol below indicates applications of acoustic emission to the component without specific reference to location of sensors.



An area of revolution subject to an internal proof test and an external eddy current test would be indicated by the symbols. No dimensions are given; therefore, the entire length is to be tested.



Direction of radiation, when specified, may be shown in conjunction with radiographic and neutron radiographic testing symbols. The direction of radiation may be indicated by a symbol located on the drawing with the desired angle indicated as follows:



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Welding Terms and Definitions

(Refer to AWS A3.0, "Standard Welding Terms and Definitions")

Actual throat. The shortest distance between the weld root and the face of a fillet weld. See Figure A1.

Adaptive control welding. Welding with a process control system that automatically determines changes in welding conditions and directs the equipment to take appropriate action. Variations of this term are **adaptive control brazing, adaptive control soldering, adaptive control thermal cutting,** and **adaptive control thermal spraying.** See also **automatic welding, manual welding, mechanized welding, robotic welding,** and **semiautomatic welding.**

Air carbon arc cutting (CAC-A). A carbon arc cutting process variation that removes molten metal with a jet of air.

Arc cutting gun. A device used to transfer current to a continuously fed cutting electrode, guide the electrode, and direct the shielding gas.

Arc seam weld. A seam weld made by an arc welding process (see Figure A2a and b).

Arc stud welding (SW). An arc welding process that uses an arc between a metal stud, or similar part, and the other workpiece. The process is used without filler metal, with or without shielding gas or flux, with or without partial shielding from a ceramic or graphite ferrule surrounding the stud, and with the application of pressure after the faying surfaces are sufficiently heated.

Arc welding electrode. A component of the welding circuit through which current is conducted and which terminates at the arc.

Arc welding gun. A device used to transfer current to a continuously fed consumable electrode, guide the electrode, and direct the shielding gas.

Arc welding torch. A device used to transfer current to a fixed welding electrode, position the electrode, and direct the flow of shielding gas.

Automatic welding. Welding with equipment that requires only occasional or no observation of the welding, and no manual adjustment of the equipment controls. Variations of this term are **automatic brazing, automatic soldering, automatic thermal cutting,** and **automatic thermal spraying** (see Figure A3). See also **adaptive control welding, manual welding, mechanized welding, robotic welding,** and **semiautomatic welding.**

Auxiliary magnifier. An additional lens used to magnify the field of vision.

Backgouging. 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.

Backhand welding. A welding technique in which the welding torch or gun is directed opposite to the progress of welding (see Figure A4). See also **travel angle, work angle,** and **drag angle.**

Backing. A material or device placed against the back side of the joint, or at both sides of a weld in electroslag and electrogas welding, to support and retain molten weld metal. The material may be partially fused or remain unfused during welding and may be either metal or nonmetal (see Figures A5d and A6).

Back weld. A weld made at the back of a single groove weld (see Figure A7d).

Bare electrode. A filler metal electrode that has been produced as a wire, strip, or bar with no coating or covering other than that which is incidental to its manufacture or preservation.

Bevel angle. The angle between the bevel of a joint member and a plane perpendicular to the surface of the member (see Figure A8).

Bond line, *thermal spraying.* The cross section of the interface between a thermal spray deposit and the substrate (see Figure A9b).

Braze welding (BW). A welding process variation that uses a filler metal with a liquidus above

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450 °C (840 °F) and below the solidus of the base metal. The base metal is not melted. Unlike brazing, in braze welding, the filler metal is not distributed in the joint by capillary action. See also **flow welding**.

Brazing (B). A group of welding processes that produces coalescence of materials by heating them to the brazing temperature in the presence of a filler metal having a liquidus above 450 °C (840 °F) and below the solidus of the base metal. The filler metal is distributed between the closely filled faying surfaces of the joint by capillary action (see Figure 1).

Brazing filler metal. The metal or alloy used as a filler metal in brazing, which has a liquidus above 450 °C (840 °F) and below the solidus of the base metal.

Buildup. A surfacing variation in which surfacing material is deposited to achieve the required dimensions. See also **buttering**, **cladding**, and **hardfacing**.

Burn through. A nonstandard term when used for excessive melt-through or a hole through a root bead.

Buttering. A surfacing variation that deposits surfacing metal on one or more surfaces to provide metallurgically compatible weld metal for the subsequent completion of the weld. See also **buildup**, **cladding**, and **hardfacing**.

Carbon electrode. A nonfiller metal electrode used in arc welding and cutting, consisting of a carbon or graphite rod, which may be coated with copper or other materials.

Cladding. A surfacing variation that deposits or applies surfacing material usually to improve corrosion or heat resistance. See also **buildup**, **buttering**, and **hardfacing**.

Composite electrode. A generic term for multicomponent filler metal electrodes in various physical forms such as stranded wires, tubes, and covered wire. See also **covered electrode**, **flux cored electrode**, **metal cored electrode**, and **stranded electrode**.

Concavity. The maximum distance from the face of a concave fillet weld perpendicular to a line joining the weld toes (see Figure A1b).

Consumable guide electroslag welding. An electroslag welding process variation in which filler metal is supplied by an electrode and its guiding member.

Consumable insert. Filler metal that is placed at the joint root before welding, and is intended to be completely fused into the joint root to become part of the weld.

Convexity. The maximum distance from the face of a convex fillet weld perpendicular to a line joining the weld toes (see Figure A1a).

Corrective lens. A lens ground to the wearer's individual corrective prescription.

Covered electrode. A composite filler metal electrode consisting of a core of a bare electrode or metal cored electrode to which a covering sufficient to provide a slag layer on the weld metal has been applied. The covering may contain materials providing such functions as shielding from the atmosphere, deoxidation, and arc stabilization, and can serve as a source of metallic additions to the weld.

Cutting electrode. A nonfiller metal electrode used in arc culling. See also **carbon electrode**, **metal electrode**, and **tungsten electrode**.

Defect. A discontinuity or discontinuities that by nature or accumulated effect (for example total crack length) render a part or product unable to meet minimum applicable acceptance standards or specifications. The term designates rejectability. See also **discontinuity** and **flaw**.

Depth of fusion. The distance that fusion extends into the base metal or previous bead from the surface melted during welding.

Diffusion aid. A solid filler metal applied to the faying surfaces to assist in diffusion welding.

Dilution. The change in chemical composition of a welding filler metal caused by the admixture

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of the base metal or previous weld metal in the weld bead. It is measured by the percentage of base metal or previous weld metal in the weld bead (see Figure A7l).

Direct current electrode negative (DCEN). The arrangement of direct current arc welding leads in which the electrode is the negative pole and workpiece is the positive pole of the welding arc (see Figure A10b).

Direct current electrode positive (DCEP). The arrangement of direct current arc welding leads in which the electrode is the positive pole and the workpiece is the negative pole of the welding arc (see Figure A10a).

Discontinuity. An interruption of the typical structure of a material, such as a lack of homogeneity in its mechanical, metallurgical, or physical characteristics. A discontinuity is not necessarily a defect. See also **defect** and **flaw.**

Drag angle. The travel angle when the electrode is pointing in a direction opposite to the progression of welding. This angle can also be used to partially define the position of guns, torches, rods, and beams (see Figure A4). See also **backhand welding, push angle, travel angle,** and **work angle.**

Effective throat. The minimum distance minus any convexity between the weld root and the face of a fillet weld (see Figure A1).

Electrode. A component of the electrical circuit that terminates at the arc, molten conductive slag, or base metal. See **cutting electrode, tungsten electrode,** and **welding electrode.**

Electrode extension. For gas metal arc welding, flux cored arc welding, and submerged arc welding, the length of electrode extending beyond the end of the contact tube (see Figure A11).

Electron beam gun. A device for producing and accelerating electrons. Typical components include the emitter (also called the filament or cathode) that is heated to produce electrons via thermionic emission, a cup (also called the grid or grid cup), and the anode.

Electroslag welding (ESW). A welding process that produces coalescence of metals with molten slag that melts the filler metal and the surfaces of the workpieces. The weld pool is shielded by this slag, which moves along the full cross section of the joint as welding progresses. The process is initiated by an arc that heats the slag. The arc is then extinguished by the conductive slag, which is kept molten by its resistance to electric current passing between the electrode and the workpieces. See also **electroslag welding electrode** and **consumable guide electroslag welding.**

Electroslag welding electrode. A filler metal component of the welding circuit through which current is conducted from the electrode guiding member to the molten slag.

Emissive electrode. A filler metal electrode consisting of a core of a bare electrode or a composite electrode to which a very light coating has been applied to produce a stable arc.

Face of weld. See **weld face.**

Face reinforcement. Weld reinforcement on the side of the joint from which welding was done (see Figures A7a and c). See also **root reinforcement.**

Ferrite number (FN). An arbitrary, standardized value designating the ferrite content of an austenitic stainless steel weld metal. It should be used in place of percent ferrite or volume percent ferrite on a direct replacement basis.

Filler metal. The metal or alloy to be added in making a welded, brazed, or soldered joint. See also **brazing filler metal, consumable insert, diffusion aid, solder, welding electrode, welding filler metal, welding rod,** and **welding wire.**

Fillet weld. A weld of approximately triangular cross section joining two surfaces approximately at right angles to each other in a lap joint, T-joint, or corner joint (see Figures 3b, A7e, A7j, and A1a-e).

Fillet weld leg. The distance from the joint root to the toe of the fillet weld (see Figures A1a-e).

Filter plate. An optical material that protects the eyes against excessive ultraviolet, infrared, and visible radiation.

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Flat welding position. The welding position used to weld from the upper side of the joint at a point where the weld axis is approximately horizontal, and the weld face lies in an approximately horizontal plane (see Figures 2, 3, 4a, and A16f).

Flaw. An undesirable discontinuity. See also **defect.**

Flux cored arc welding (FCAW). An arc welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding gas from a flux contained within the tubular electrode, with or without additional shielding from an externally supplied gas, and without the application of pressure. See also **flux cored electrode.**

Flux cored electrode. A composite tubular filler metal electrode consisting of a metal sheath and a core of various powdered materials, producing an extensive slag cover on the face of a weld bead. External shielding may be required.

Forehand welding. A welding technique in which the welding torch or gun is directed toward the progress of welding (see Figure A4). See also **travel angle, work angle,** and **push angle.**

Fusion, *fusion welding.* The melting together of filler metal and base metal, or of base metal only, to produce a weld. See also **depth of fusion.**

Gas metal arc welding (GMAW). An arc welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used without shielding from an externally supplied gas and with the application of pressure. See also **pulsed gas metal arc welding** and **short circuit gas metal arc welding.**

Gas tungsten arc welding (GTAW). An arc welding process that uses an arc between a tungsten electrode (nonconsumable) and the weld pool. The process is used with shielding gas and without the application of pressure. See also **hot wire welding** and **pulsed gas tungsten arc welding.**

Globular transfer, *arc welding.* The transfer of molten metal in large drops from a consumable electrode across the arc (see Figure A11a). See also **short circuiting transfer** and **spray transfer.**

Groove angle. The total included angle of the groove between workpieces (see Figure A8).

Groove weld. A weld made in a groove between the workpieces (see Figures A5, A12, and A4a).

Groove weld size. The joint penetration of a groove weld (see Figure A12).

Ground lead. A nonstandard and incorrect term for **workpiece lead.**

Gun. See **arc cutting gun, arc welding gun, electron beam gun, resistance welding gun,** and **thermal spraying gun.**

Hardfacing. A surfacing variation in which surfacing material is deposited to reduce wear. See also **buildup, buttering,** and **cladding.**

Heat-affected zone. The portion of the base metal whose mechanical properties or micro structure have been altered by heat of welding, brazing, soldering, or thermal culling (see Figure A7g).

Heating torch. A device for directing the heating flame produced by the controlled combustion of fuel gases.

High frequency resistance welding. A group of resistance welding process variations that use high frequency welding current to concentrate the welding heat at the desired locations (see Figure A14). See also **high frequency seam welding** and **high frequency upset welding.**

High frequency seam welding (RSEW-HF). A resistance seam welding process variation in which high frequency welding current is supplied through electrodes into the workpieces (see Figure A14c). See also **high frequency resistance welding** and **induction seam welding.**

High frequency upset welding (UW-HF). An upset welding process variation in which frequency welding current is supplied through electrodes into the workpieces (see Figure A14). See also **high**

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frequency resistance welding and **induction upset welding**.

Horizontal welding position, *fillet weld*. The welding position in which the weld is on the upper side of an approximately horizontal surface and against an approximately vertical surface (see Figures 2 and 3b).

Horizontal welding position, *groove weld*. The welding position in which the weld face lies in an approximately vertical plane and the weld axis at the point of welding is approximately horizontal (see Figures 2, 3a, 4b, and A16f).

Hot wire welding. A variation of a fusion welding process in which a filler metal wire is resistance heated by current flowing through the wire as it is fed into the weld pool.

Included angle. A nonstandard term for **groove angle**.

Incomplete fusion. A weld discontinuity in which fusion did not occur between weld metal and fusion faces or adjoining weld beads.

Incomplete joint penetration. A joint root condition in a groove weld in which weld metal does not extend through the joint thickness (see Figure A12).

Induction seam welding (RSEW-I). A resistance seam welding process variation in which high frequency welding current is induced in the workpieces. See also **high frequency resistance welding** and **high frequency seam welding**.

Induction upset welding (UW-I). An upset welding process variation in which high frequency welding current is induced in the workpieces (see Figure A14e). See also **high frequency resistance welding** and **high frequency upset welding**.

Interpass temperature, *thermal spraying*. In multipass thermal spraying, the temperature of the thermal spray area between thermal spray passes.

Interpass temperature, *welding*. In a multipass weld, the temperature of the weld area between weld passes.

Joint. The junction of members or the edges of members that are to be joined or have been joined (see Figures 6 and A15).

Joint clearance, *brazing and soldering*. The distance between the faying surfaces of a joint.

Joint design. The joint geometry together with the required dimensions of the welded joint.

Joint efficiency. The ratio of strength of a joint to the strength of the base metal, expressed in percent.

Joint penetration. The distance the weld metal extends from the weld face into a joint, exclusive of weld reinforcement (see Figures A1g and A12). See also **groove weld size**.

Joint root. That portion of a joint to be welded where the members approach closest to each other. In cross section, the joint root may be either a point, a line, or an area (see Figure A17).

Lack of fusion. A nonstandard term for **incomplete fusion**.

Lack of penetration. A nonstandard term for **incomplete joint penetration**.

Lap joint. A joint between two overlapping members in parallel planes (see Figures 6d and A14c).

Leg of a fillet weld. See **fillet weld leg**.

Lens. See **filter plate**.

Lightly coated electrode. A filler metal electrode consisting of a metal wire with a light coating applied subsequent to the drawing operation, primarily for stabilizing the arc.

Machine welding. A nonstandard term when used for **mechanized welding**.

Manual welding. Welding with the torch, gun, or electrode holder held and manipulated by hand. Variations of this term are **manual brazing**, **manual soldering**, **manual thermal cutting**, and **manual**

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