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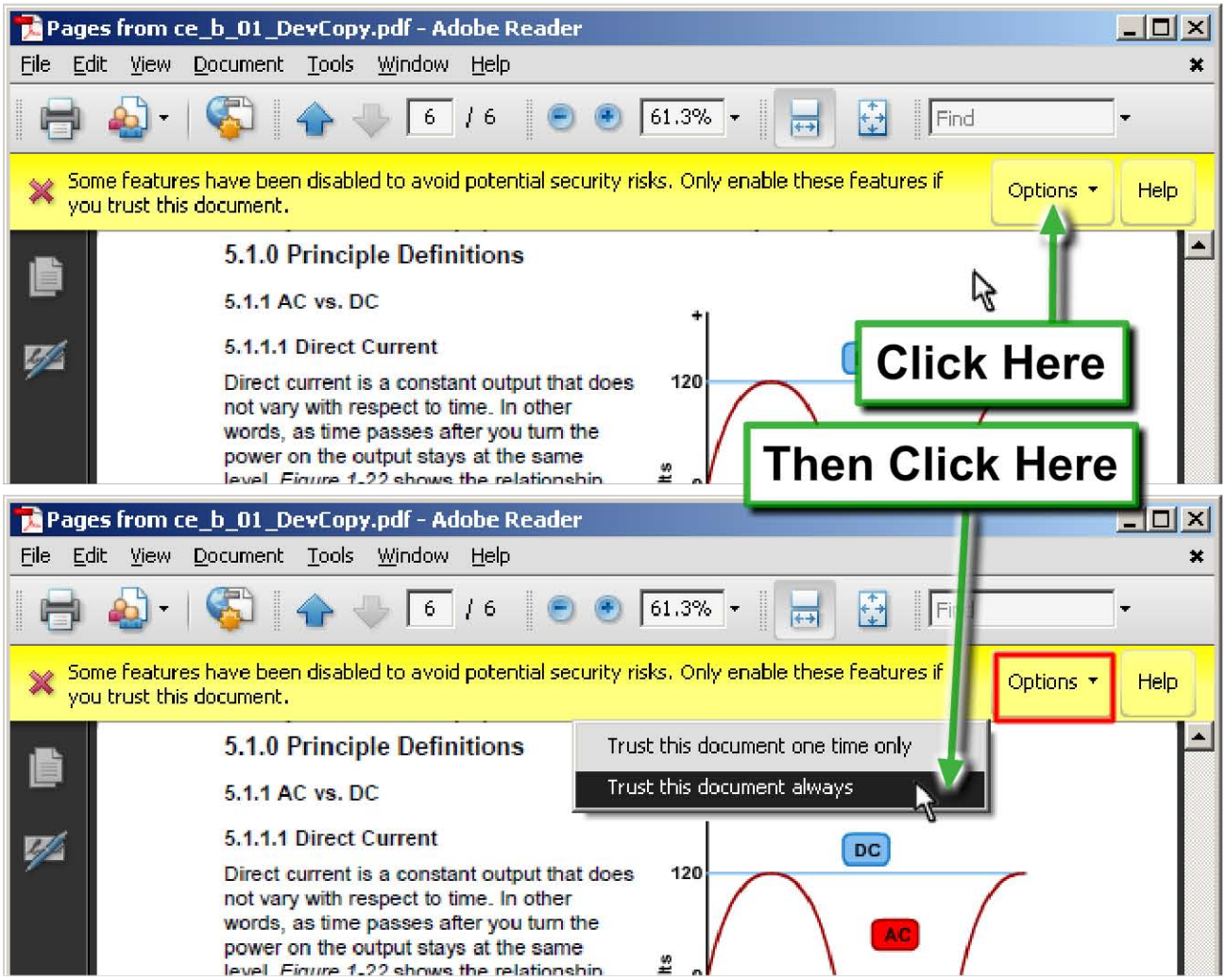

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CHAPTER 6

NONDESTRUCTIVE INSPECTIONS, WELDING, AND HEAT TREATMENT

INTRODUCTION

The basic principles and procedures of nondestructive inspections, welding, and the heat treatment of metals are covered in this course. These three areas require special training, and in the case of nondestructive inspections (NDI) and welding, they require special certification prior to performing these two functions. While not all aviation structural mechanics (AMs) are required to become NDI technicians, aeronautical equipment welders, or have the need to perform heat treatment of metal, there is the need to be familiar with these procedures and how they apply to the AM rate. The information in these areas is being presented in a broad nature. For a more detailed discussion of these procedures, refer to the applicable technical manuals.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Evaluate the background and personnel training required for the NDI program. Identify various NDI personnel qualifications.
2. Recognize the qualifications and recertification process to become a certified welder. Identify the different types of welding processes. Identify various equipment and materials used in welding.
3. Recognize the principles of heat treatment. Identify the most common forms of heat treatment.

NONDESTRUCTIVE INSPECTION PROGRAM

In the hands of a trained and experienced technician, NDI methods allow detection of flaws or defects in materials with a high degree of accuracy and reliability. It is important that mechanics become fully knowledgeable of the capabilities of each NDI method, but it is equally important to recognize the limitations of these methods. The nondestructive inspection methods covered in this chapter serve as tools of prevention, which allow defects to be detected before they develop into serious failures.

During the inspection of aircraft, it is essential that faults are found and corrected before they reach catastrophic proportions. In applicable areas, NDI can provide 100-percent sampling with no affect upon the use of the part or system being inspected. The effective use of NDI will result in increased operational safety, and in many instances, dramatically reduce maintenance man-hour expenditures.

NDI is the practice of evaluating a part or sample of material without impairing its future usefulness. The methods used in naval aviation include, but are not limited to, visual or optical, liquid penetrant, magnetic particle, eddy current, ultrasonic, and radiographic. The success in their use depends heavily upon intelligent application and discriminating interpretation of results.

NDI is performed only by qualified and currently certified NDI personnel in accordance with *Nondestructive Inspection Methods, Basic Theory* NAVAIR 01-1A-16-1 and *General Procedures and Process Controls* NAVAIR 01-1A-16-2 manuals. These are general manuals covering the theory, general applications, procedures and process control of the various methods of NDI.

The Aircraft Nondestructive Inspection School, located at Naval Air Technical Training Center (NATTC) Pensacola, Florida, provides NDI technician training for both military and civil service personnel. Career designated (grade E-4 and above) Navy AMs, Marine Corps structural mechanics, and equivalent civil service personnel are eligible for the course. In addition, NDI operator training in liquid penetrant, magnetic particle, and eddy current methods; refresher training; and recertification of NDI technicians are provided by the Naval Aviation Depot (NADEP) and aircraft controlling custodian or type commander (ACC/TYCOM) designated NDI specialists. Requests for NADEP training and authorization for recertification of NDI technicians who have been inactive in NDI for more than one year must be made, via the chain of command, to the cognizant ACC/TYCOM. If the request is approved, the ACC/TYCOM will advise which NADEP is to be used.

NDI PERSONNEL

Before candidates are selected for NDI technician or operator training, and annually thereafter, they are required to have an eye examination. Military and civilian NDI personnel are identified as NDI specialists, technicians, or as operators.

NDI Specialists

NDI specialists are authorized by the ACC to provide training and certification/recertification of NDI technicians/operators. They also provide technical NDI services.

NDI Technicians

NDI technicians are personnel who have successfully completed the NDI course (C-603-3191) at Aircraft Nondestructive Inspection School at NATTC Pensacola, Florida. NDI technicians are assigned NEC 7225, and they are qualified and certified to perfrom liquid penetrant, magnetic particle, eddy current, ultrasonic, and radiographic methods of NDI. These personnel are normally assigned to intermediate maintenance activities (IMAs). Any NDI technician with three or more years of experience and who are currently certified and engaged in NDI on a regular basis may be authorized by ACCs to train and certify NDI operators for specific NDI applications. The ACC may also waive the 3-year experience requirement provided requests for this authorization are addressed to the ACC/TYCOM via the appropriate wing.

This request must include the technician's current qualification, experience history, and the specific technical directive/technical publication-directed NDI applications for which operator certification is to be provided. If approved, a copy of the ACC authorization will be attached to the technician's NDI certification record and maintained with his/her individual NDI record. Such authorizations remain in effect only as long as the currency of certification and NDI experience is maintained. Currently active NDI technicians require recertification every three years.

Early recertification is authorized and encouraged to prevent expiration of certification during tours of deployed duty. Current certification of NDI technicians who are regularly

engaged in all methods of NDI may be extended by ACCs for up to one year if circumstances warrant. NEC 7225 personnel who have been inactive in NDI for one year or more require recertification before resuming active NDI technician status. Recertification is provided by designated NADEPs or by ACC designated and qualified Naval Aviation Engineering Services Unit (NAESU) Navy federal civilian or military technical specialists.

NDI Operators

NDI operators are military personnel E-4 and above, or civilian equivalent, who have successfully completed training and are certified to perform specific NDI tasks using one or more of the following methods: liquid penetrant, eddy current, or magnetic particle. NDI operators may be assigned and used in IMAs to perform specific publication-directed NDI tasks only when the NDI workload exceeds the capacity of assigned NDI technicians. Each case of NDI operator use at I-level maintenance must be authorized by the cognizant ACC. Requests for such authorizations are made to the ACC via the appropriate wing.

Basic NDI operator training is provided by NADEPs and NDI specialists. When training is not available, ACCs may authorize the training of NDI operators by NDI technicians in specific liquid penetrant kit applications. NDI operator certification/recertification is provided by NDI specialists and NDI technicians. Recertification of NDI operators is required annually. NDI operators at I-level activities must be closely monitored by qualified NDI technicians and by cognizant QARs/CDQARs. NDI operators are not authorized to operate radiographic or ultrasonic equipment. They may, however, be used to assist NDI technicians operating such equipment.

All NDI technicians and operators must use the NDI method or methods for which they are certified at least two times each month, as evidenced by entries on their work record (COMNAVAIRFORINST 4790/140). This can be done either through normal workload or practice applications. In those cases where the prescribed proficiency is not maintained for one or more months, technicians or operators can regain proficiency by making practice applications under the supervision of a certified NDI technician, who will provide recertification upon determination of proficiency. Failure to maintain proficiency for six months for NDI operators and twelve months for NDI technicians will require updated training for recertification. Any NDI technician who fails to maintain proficiency for three years or more will require complete retraining. In all cases exceeding six months for operators and twelve months for technicians, authorization for updated training or complete retraining is requested from the cognizant ACC.

Activities that are authorized to certify/recertify NDI technicians and operators must administer an appropriate written test on the NDI methods involved. The *Nondestructive Inspection Methods, Basic Theory* NAVAIR 01-1A-16-1 and *General Procedures and Process Controls* NAVAIR 01-1A-16-2 manuals are the source for test questions. Personnel being certified or recertified will also be required to demonstrate the ability to perform NDI inspections as appropriate. The objective is to provide sufficient testing of the candidate to ensure the person is competent to conduct NDIs.

The effectiveness of the NDI program can be enhanced through development of new NDI techniques/applications by efficient and inventive NDI personnel. Useful new techniques, so developed, will be submitted to the appropriate CFA for approval and distribution to other fleet activities. An information copy is submitted to the ACC NDI specialist.

NDI CERTIFICATION RECORD

The NDI Certification Record in *Figure 6-1* provides a record of certification. The original copy goes to the individual, with one copy each to quality assurance/analysis (QA/A) and the division officer. All certified NDI personnel must initiate and maintain individual records of NDI performed.

OPNAVINST 4790.2H

NDI CERTIFICATION RECORD

1. NAME	2. RATE/RANK
3. CERTIFYING ACTIVITY	
4. EFFECTIVE DATE	5. RECERTIFICATION DUE DATE

6. THIS INDIVIDUAL IS CERTIFIED TO CONDUCT NDI BY USE OF THE FOLLOWING METHOD(S):

- ☐ RADIOGRAPHY
- ☐ EDDY CURRENT
- ☐ LIQUID PENETRANT
- ☐ ULTRASONIC
- ☐ MAGNETIC PARTICLE
- ☐ OTHER *(Specify in remarks)*

7. REMARKS:

8. SIGNATURE *(Certifying Official)*	9. DATE

Original to: Individual's Qualification/Certification Record

OPNAV 4790/139 (2-01) S/N 0107-LF-983-3000

Figure 6-1 — NDI Certification Record (OPNAV 4790/139).

NDI TECHNICIAN/OPERATOR WORK RECORD

This form (*Figure 6-2*) is used to record and verify NDI performed. Entries will be verified by the individual's work center supervisor, or, if the work center supervisor performs the NDI, by QA/A. Personnel doing repetitive NDI, such as eddy current on aircraft wheels, may record weekly entries, as indicated on the sample entry in *Figure 6-2*. Upon transfer, NDI work records are carried by the individual to his/her next command.

OPNAVINST 4790.2C

NDI TECHNICIAN/OPERATOR WORK RECORD

1. NAME	2. RATE/RANK
3. ORGANIZATION	
4. DATE IN	5. DATE OUT

6. DATE	7. NDI METHOD	8. HRS	9. REMARKS	10. VERIFIED

OPNAV 4790/140(2-84) S/N 0107-LF-047-9700

Figure 6-2 — NDI Technician/Operator Work Record (OPNAV 4790/140).

NDI PROGRAM RESPONSIBILITIES

All NDI is of vital concern at all levels of maintenance, and all operational and support commanders should direct their efforts toward its proper use. NDI is used in the maintenance of Navy aircraft and aircraft systems wherever contributions to safety, reliability, QA, performance, or economy can be realized.

Naval Air Systems Command

The Naval Air Systems Command (NAVAIR) has cognizance over the NDI program. They are responsible for managing a program of research, development, training, and application of NDI techniques and equipment. The NAVAIR Instruction (NAVAIRINST) 13070.1A assigns the responsibility for nondestructive testing and inspection within NAVAIR. NAVAIR is responsible for the following:

1. Coordinating and issuing information on NDI within naval aviation, other services, and industry, as appropriate
2. Ensuring appropriate application of NDI at all levels of maintenance
3. Procuring NDI equipment to support an effective program
4. Procuring NDI technical publications and ensuring updating of such publications as newer techniques and applications are developed
5. Establishing the necessary standards and specifications for NDI
6. Monitoring, evaluating, and standardizing the NADEPs NDI program
7. Providing NDI training for the NADEPs, as requested
8. Assigning an NDI program coordinator to be responsible for managing implementation of the application and training elements

Aircraft Controlling Custodians

Aircraft controlling custodians (ACCs) are responsible for the following:

1. Monitoring the NDI program in activities under their cognizance
2. Advising on availability and location of NDI training
3. Maintaining liaison with NAVAIR, NADOC, Naval Aviation Maintenance Office (NAMO), NADEPs, and fleet activities on NDI matters
4. Ensuring that NDI laboratories, equipment, and personnel are audited as required
5. Designating NDI specialists, as required
6. Designating an NDI program manager

Intermediate Maintenance Activities

Intermediate maintenance activities (IMAs) are responsible for the following:

1. Ensuring compliance with qualification requirements and safety precautions
2. Ensuring industrial radiation safety requirements are strictly enforced in accordance with the *Radiological Affairs Support Program (RASP)*, NAVSEA S0420-AA-RAD-010, manual.

3. Fully using available NDI equipment, and developing new procedures and applications—as far as practical—to provide labor, material, and cost savings
4. Maintaining an adequate number of certified and proficient NDI technicians at all times to provide NDI services to supported organizations and transient aircraft
5. Ensuring the material condition of NDI equipment and the laboratory is continuously "ready for use" (RFU) including availability of consumable items
6. Establishing and maintaining a continuing training program within the NDI work center to allow NDI technicians to remain up to date with newly developed NDI techniques and applications
7. Establishing and maintaining liaison with the cognizant ACC NDI specialist, and requesting assistance via the chain of command on all NDI problems
8. Providing and maintaining industrial X-ray film processing facilities, both ashore and afloat
9. Providing scheduled and unscheduled NDI support to O-level activities, as required
10. Maintaining liaison with ship/station radiation officer

Quality Assurance/Analysis

Quality assurance/analysis (QA/A) is responsible for the following:

1. Monitoring compliance with NDI personnel qualifications, certification/recertification requirements, safety precautions, and instructions
2. Monitoring the organization's NDI training program to ensure it is current and comprehensive with special emphasis placed on those areas of NDI that are accomplished by personnel other than those assigned Navy enlisted classification (NEC) 7225

Organizational Maintenance Activities

O-levels are responsible for the following:

1. Requesting NDI I-level support as required
2. Obtaining IMA NDI services in all situations where NDI results are suspicious
3. Having an NDI technician verify defects discovered by an NDI operator, whenever possible
4. Informing the IMA, in advance, of scheduled NDI requirements with these requirements included in the monthly maintenance plan

O-level NDI technicians may be assigned to the supporting IMA, as necessary, to maintain their proficiency and to augment IMAs NDI capabilities.

NDI INSPECTION METHODS

The various NDI methods serve as tools of prevention that allow defects to be detected before they develop into serious or hazardous failures. With the NDI methods, a trained and experienced technician can detect flaws or defects with a high degree of accuracy and reliability. It is important that technicians become fully knowledgeable of the capabilities of each method. It is equally important that they recognize the limitations of the methods. Some of the defects found by NDI include corrosion, leaks, pitting,

heat/stress cracks, and discontinuity of metals. The following paragraphs will give a brief synopsis of the various NDI inspections. For further information on NDI procedures, you should consult the *General Procedures and Process Controls* NAVAIR 01-1A-16-2, manual or the appropriate inspection manual pertaining to the type of aircraft or part that is to be inspected by an NDI method.

Magnetic Particle Inspection

Magnetic particle inspection is a rapid, nondestructive means of detecting discontinuities in parts made of ferromagnetic materials. If the part is made from an alloy that contains a high percentage of iron and can be magnetized, it is in a class of metals called "ferromagnetic," and it can be inspected by this method. If the part is made of material that is nonmagnetic, it cannot be inspected by this method. The magnetic particle inspection method will detect surface discontinuities, including those that are too fine to be seen with the naked eye and subsurface discontinuities, those that lie slightly below the surface, and, when special equipment is used, the more deeply seated discontinuities.

The inspection process consists of inducing a magnetic field into a part and applying magnetic particles, in liquid suspension or dry powder, to the surface being inspected. When the magnetic field is interrupted by a discontinuity, some of the field is forced out into the air above the discontinuity, forming a leakage field. The leakage field will be stronger and more concentrated the closer the discontinuity is to the surface. The presence of a discontinuity is detected by the ferromagnetic particles applied over the surface. Some of these particles will be gathered and held by the leakage field. This magnetically held collection of particles forms an outline of the discontinuity and indicates its location, size, and shape.

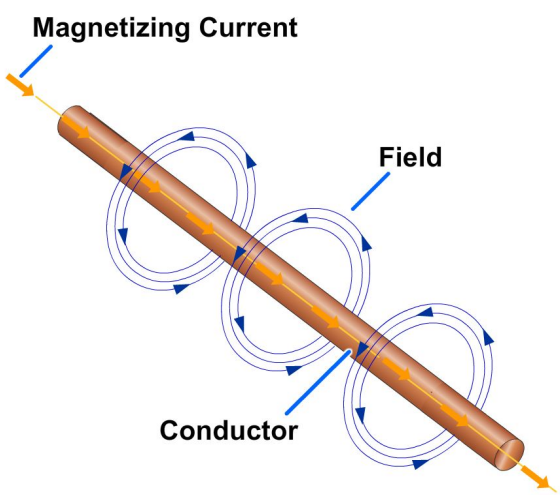


Figure 6-3 — Magnetic field surrounding an electrical conductor.

Electric current is used to create or induce magnetic fields in magnetic materials. The magnetic lines of force are always aligned at right angles (90°) to the direction of the current flow. The direction of the magnetic field can be altered, and it is controlled by the direction of the magnetizing current. The arrangement of the current paths is used to induce the magnetic lines of force so they intercept and are as near as possible at right angles to the discontinuity.

The magnetic field must be in a favorable direction to produce indications. When the flux lines are oriented in a direction parallel to a discontinuity, the indication will be weak or lacking. The best results are obtained when the flux lines are in a direction at right angles to the discontinuity. If a discontinuity is to produce a leakage field and a readable magnetic particle indication, the discontinuity must intercept the flux lines of force at some angle. When an electrical magnetizing current is used, the best indications are produced when the path of the magnetizing current is flowing parallel to the discontinuity, because the magnetic flux lines are always at an angle of 90° to the flow of the magnetizing current. The two types of magnetizing methods used are circular and longitudinal.

CIRCULAR MAGNETIZATION — Circular magnetization is used for the detection of radial discontinuities around edges of holes or openings in parts. It is also used for the detection of longitudinal discontinuities, which lie in the same direction as the current flow either in a part or in a part that a central conductor passes through.

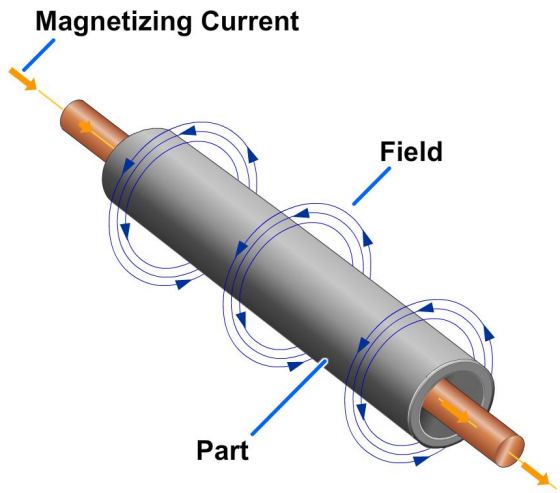


Figure 6-4 — Magnetic field in part used as a conductor.

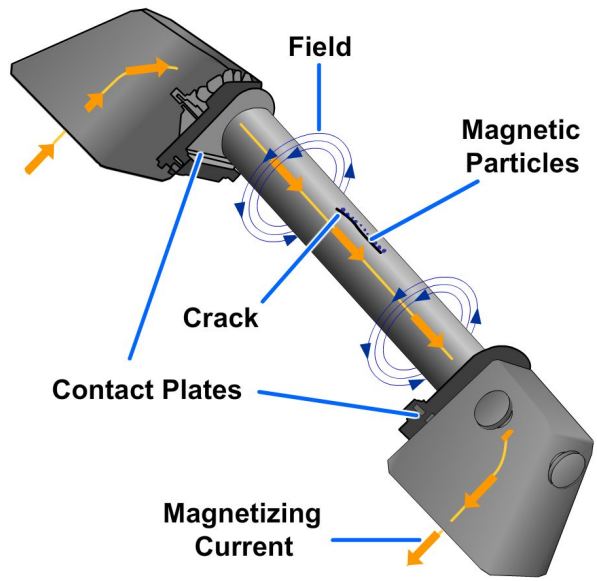


Figure 6-5 — Creating a circular magnetic field in a part.

Circular magnetization derives its name from the fact that a circular magnetic field always surrounds a conductor, such as a wire or a bar carrying an electric current (*Figure 6-3*). The direction of the magnetic lines of force (magnetic field) is always at right angles to the direction of the magnetizing current. An easy way to remember the direction of magnetic lines of force around a conductor is to imagine that you are grasping the conductor with your hand so that the extended thumb points parallel to the electric current flow. The fingers then point in the direction of the magnetic lines of force. Conversely, if the fingers point in the direction of current flow, the extended thumb points in the direction of the magnetic lines of force.

Since a magnetic part is in effect a large conductor, electric current passing through this part creates a magnetic field in the same manner as with a small conductor (*Figure 6-4*). The magnetic lines of force are at right angles to the direction of the current as before. This type of magnetization is called "circular magnetization" because the lines of force, which represent the direction of the magnetic field, are circular within the part.

To create or induce a circular field in a part with stationary magnetic particle inspection equipment, the part is clamped between the

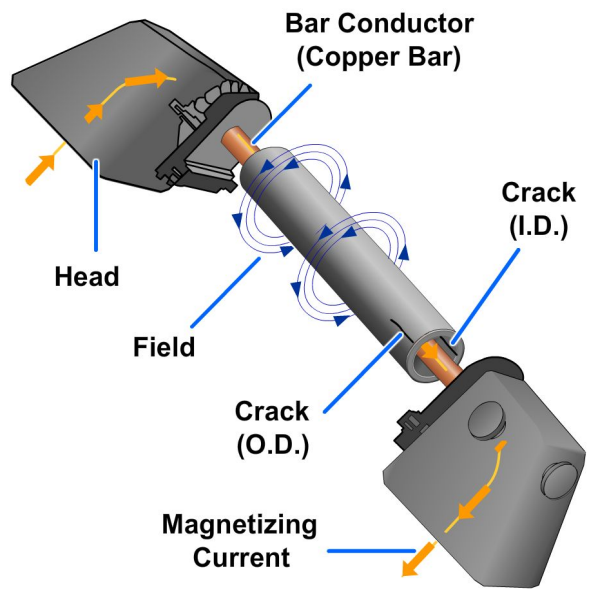


Figure 6-6 — Using a central conductor to circularly magnetize a cylinder.

contact plates and current is passed through the part, as indicated in *Figure 6-5*. This sets up a circular magnetic field in the part that creates poles on either side of any crack or discontinuity that runs parallel to the length of the part. The poles will attract magnetic particles, forming an indication of the discontinuity.

On parts that are hollow or tube-like, the inside surfaces are as important to inspect as the outside. When such parts are circularly magnetized by passing the magnetizing current through the part, the magnetic field on the inside surface is negligible. Since there is a magnetic field surrounding the conductor of an electric current, it is possible to induce a satisfactory magnetic field by placing the part on a copper bar or other conductor. This situation is illustrated in *Figures 6-6* and *6-7*. Passing current through the bar induces a magnetic field on both the inside and outside surfaces.

LONGITUDINAL MAGNETIZATION — Longitudinal magnetization is used for the detection of circumferential discontinuities, which lie in a direction transverse to or at approximately right angles to a parts axis. Electric current is used to create a longitudinal magnetic field in a piece of magnetic material. When a part of magnetic material is placed inside a coil, as shown in *Figure 6-8*, the magnetic lines of force created by the magnetizing current concentrate themselves in the part and induce a longitudinal magnetic field. Inspection of a cylindrical part with longitudinal magnetism is shown in *Figure 6-9*. If there is a transverse discontinuity in the part, such as that in the illustration, small magnetic poles are formed on either side of the crack. These poles will attract magnetic particles, forming an indication of the discontinuity. Compare *Figure 6-9* with *Figure 6-5*, and note that in both cases a magnetic field has been induced in the part that is at right angles to the defect. This is the most desirable condition for a reliable inspection.

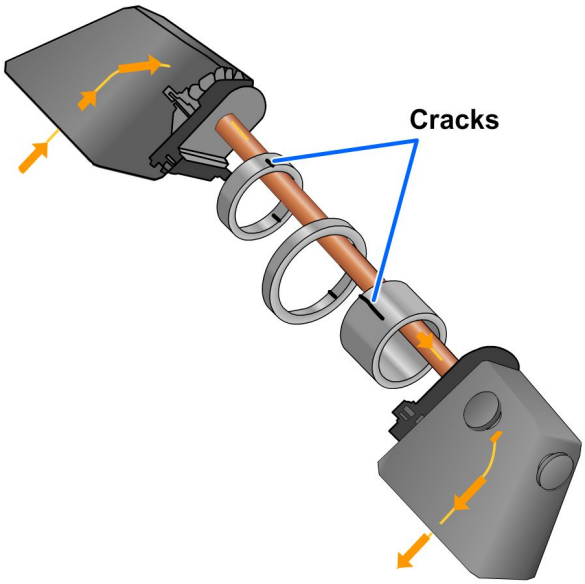


Figure 6-7 — Using a central conductor to circularly magnetize ringlike parts.

ALTERNATING CURRENT — The use of alternating current (ac) in magnetic particle inspection is recommended only for the detection of surface discontinuities, which comprise the majority of service-induced defects. Fatigue and stress corrosion cracks are examples of cracks usually open to the surface. Alternating current, which must be single phase when used directly for magnetizing purposes, is taken from commercial power lines or portable power sources, and is usually 50 or 60 hertz.

DIRECT CURRENT — Direct current (dc) magnetizes the entire cross section uniformly—more or less—in the case of longitudinal magnetization. Magnetic fields produced by direct current penetrate deeper into a part than fields produced by alternating current, which makes it possible to detect subsurface discontinuities. Generally, direct current is used with wet magnetic particle methods. In the presence of dc fields, dry powder particles behave as though they were immobile, tending to remain wherever they happen to land on the surface of a part. This is in contrast to what happens with dry powder particles in the presence of ac fields. In these fields, the particles have mobility on a surface due to the pulsating character of the fields. Particle

mobility considerably aids the formation of particle accumulations (indications) at discontinuities.

PARTICLES AND METHODS OF APPLICATION — The particles used in magnetic particle testing are made of magnetic materials, usually combinations of iron and iron oxides, that have a high permeability and low retentivity. Particles that have high permeability are easily magnetized by and attracted to the low-level leakage fields at discontinuities. Low retentivity is required to prevent the particles from being permanently magnetized. Strongly retentive particles tend to cling together and to any magnetic surface, resulting in reduced particle mobility and increased background accumulation.

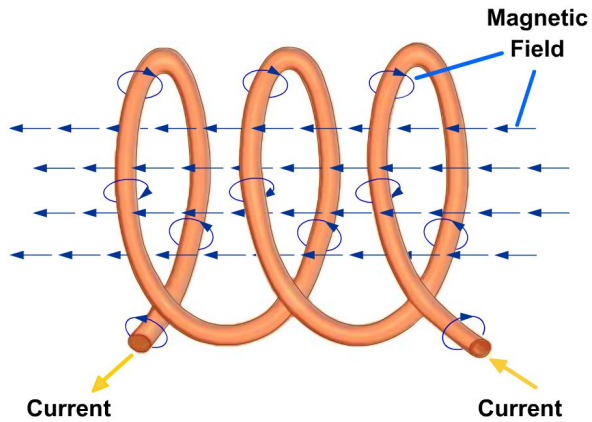


Figure 6-8 — Magnetic field in a part placed in a coil.

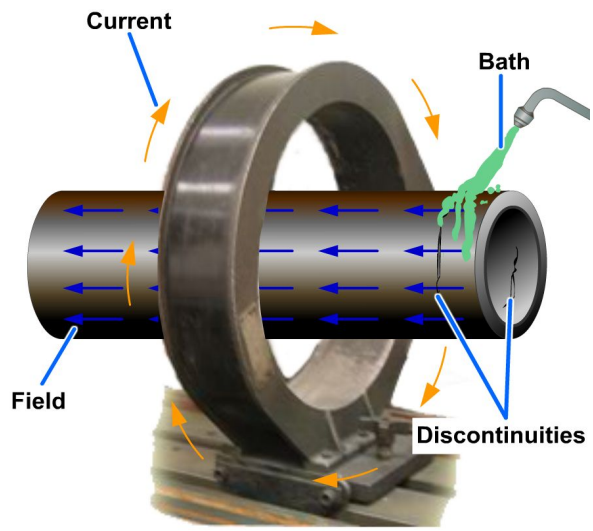


Figure 6-9 — Coil creates a longitudinal field to show crack in a part.

Particles are very small and various sizes. Each magnetic particle formulation always contains a range of sizes and shapes to produce optimum results for the intended use. The smallest particles are more easily attracted to and held by the low-level leakage fields at very fine discontinuities; larger particles can more easily bridge across coarse discontinuities, where the leakage fields are usually stronger. Elongated particles are included, particularly in the case of dry powders, because these rod-shaped particles easily align themselves with leakage fields not sharply defined, such as those that occur over subsurface discontinuities. Global-shaped particles are included to aid in the mobility and uniform dispersion of particles on a surface.

Magnetic particles may be applied as a dry powder, or wet, by using either water or a high flash point petroleum distillate as a liquid vehicle carrier. Dry powder is available in various colors, so the user can select the color that contrasts best with the color of the surface upon which it is used. Colors for use with ordinary visible light are red, grey, black, or yellow. Red- and black-colored particles are available for use in wet baths with ordinary light, and yellow-green fluorescent particles for use with a black light. Fluorescent particles are widely used in wet baths, since the bright fluorescent indications produced at discontinuities are readily seen against the dark backgrounds that exist in black light inspection areas.

Radiographic Inspection

Radiographic is a nondestructive inspection method that uses a source of X-rays to detect discontinuities in materials and assembly components. Radiation is projected through the item to be tested, and the results are captured on film. Radiography may be used on metallic, nonmetallic, and combination metallic/nonmetallic materials and assemblies without access to the interior. However, defects must be correctly aligned and oriented with respect to penetrating rays to be reliably detected. Radiography is one of the most expensive and least sensitive methods for crack detection. It should only be used to detect flaws that are not accessible or favorably oriented for use by other test methods.

The extent of recorded information is dependent upon the following three prime factors:

1. The composition of the material
2. The product of the density and the thickness of the material
3. The energy of the X-rays, which is incident upon the material as material discontinuities cause an apparent change in these characteristics, and thus make themselves detectable

Figure 6-10 is a diagram of radiographic exposure showing the elements of the system. Radiation passes through the object and produces an invisible or latent image in the film. When processed, the film becomes a radiograph or shadow picture of the object. Since more radiation passes through the object where the section is thin or where there is a space or void, the corresponding area on the film is darker. The radiograph is read or interpreted by comparing it with the known nature of the object.

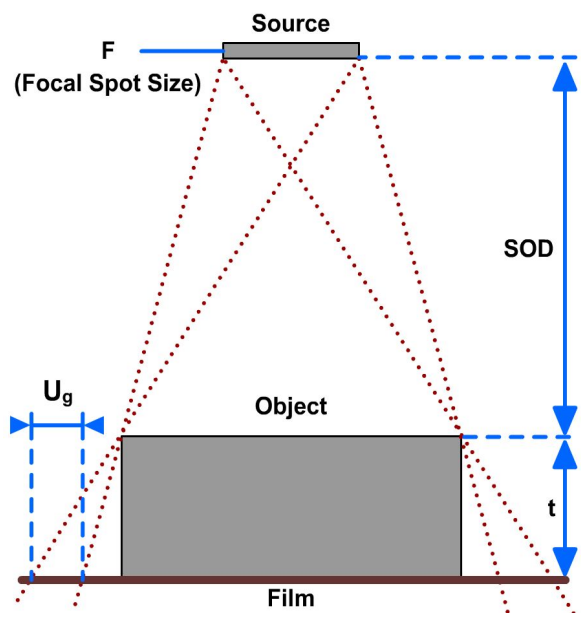


Figure 6-10 — Diagram of radiographic exposure.

RADIOGRAPHIC INTERPRETATION — The usefulness of the information obtained from the radiographic process depends upon the intelligent interpretation of the derived image. To successfully interpret the radiograph, the radiographic interpreter must have a working knowledge of the component or material and be able to relate the images to the conditions likely to occur. Specifications are used to spell out the discontinuities that maybe considered detrimental to the function of the part and the acceptable magnitudes of the discontinuities. It is the duty of the radiographic interpreter to recognize the various discontinuities, their magnitudes, and be capable of relating them to the particular specification required. The responsibility and capability of the radiographic interpreter cannot be overemphasized. Often, many human lives and investments of millions of dollars are depending on the judgment of the radiographic interpreter.

RADIATION HAZARD — Radiation from X-ray units is destructive to living tissue. It is universally recognized that in the use of such equipment, adequate protection must be provided to personnel. Personnel must keep outside the primary X-ray beam at all times.

Radiation produces changes in all matter that it passes through. This is also true of living tissue. When the radiation strikes the molecules of the body, the effect may be no more than to dislodge a few electrons; but an excess of these changes could cause irreparable harm. When a complex organism is exposed to radiation, the degree of damage, if any, depends on which of its body cells have been changed. The more vital parts are in the center of the body; therefore, the more penetrating radiation is likely to be the more harmful in these areas. The skin usually absorbs most of the radiation; therefore, it reacts earliest to radiation.

If the whole body is exposed to a very large dose of radiation, it could result in death. In general, the type and severity of the pathological effects of radiation depend on the amount of radiation received at one time and the percentage of the total body exposed. The smaller doses of radiation may cause blood and intestinal disorders in a short period of time. The more delayed effects are leukemia and cancer. Skin damage and loss of hair are also possible results of exposure to radiation.

Ultrasonic Inspection

The term *ultrasonic* means vibrations or sound waves, with frequencies greater than those that affect the human ear (greater than about 20,000 cycles per second).

Ultrasonic inspection is a method of inspection that uses these sound waves. The ultrasonic vibrations are generated by applying high-frequency electrical pulses to a transducer element contained within a search unit. The transducer element transforms the electrical energy into ultrasonic energy. The transducer element can also receive ultrasonic energy and transform it into electrical energy. Ultrasonic energy is transmitted between the search unit and the test part through a coupling medium, such as oil, as shown in *Figure 6-11*, for the purpose of excluding the air interface between the transducer and the test part. The ultrasonic vibrations are transmitted into and through the part. When the beam strikes the far surface of the part or strikes the boundary of a defect, the beam reflects back toward the transducer, travels through the couplant, and enters the transducer, where it is converted back into electrical energy. Then, the information is displayed on a cathode-ray tube (CRT) screen.

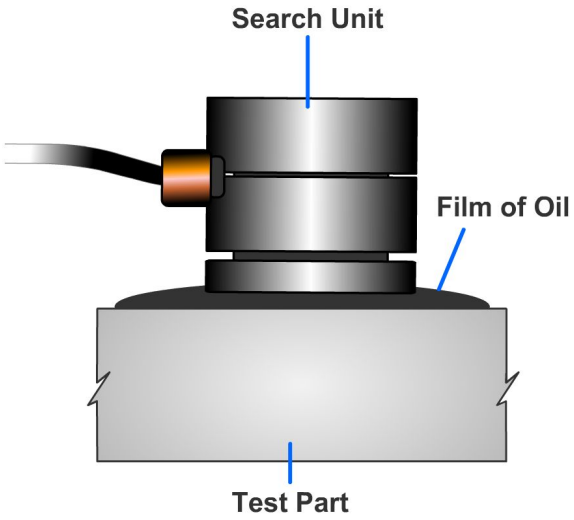


Figure 6-11 — Coupling of search unit to test part for transmission of ultrasonic energy.

Ultrasonic inspections can be separated into two basic categories—contact inspection and immersion inspection. In the contact method, the search unit is placed directly on the test part surface by using a thin film of couplant, such as oil, to transmit sound into the test part. In the immersion method, the test part is immersed in a fluid, usually water, and the sound is transmitted through the water to the test part (*Figure 6-12*). The immersion-type method is used to inspect materials while they are immersed in a suitable liquid, such as water or oil. This method proves more satisfactory than contact testing for irregular-shaped surfaces. Immersion inspection also permits use of a wider range of testing frequencies. The three general methods of contact inspections are straight-beam, angle-beam, and the surface-wave method.

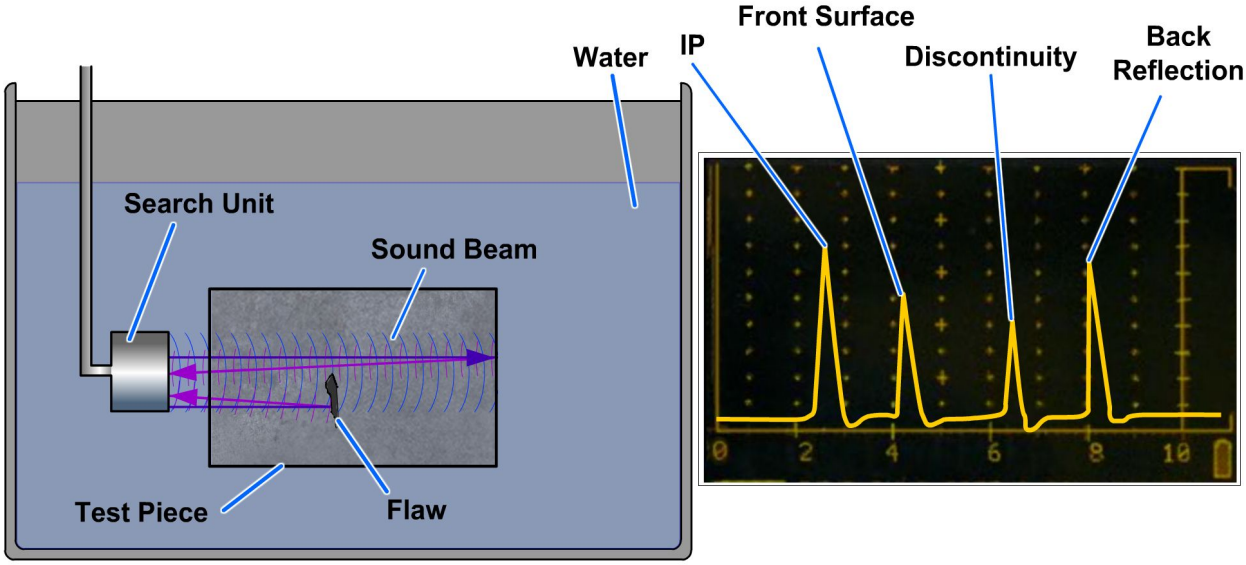


Figure 6-12 — Immersion method.

STRAIGHT BEAM — The straight-beam method is used to detect discontinuities parallel to the test surface, and is generally used on material 1/2 inch thick or greater. Most straight-beam methods are applied by using the pulse-echo technique (transmitting and receiving search unit or units placed on the same surface). Certain applications use the through-transmission method (transmitting search unit placed on one surface, and receiving search unit placed on the opposite surface). In the through-transmission method, discontinuities block the passage of sound. This results in a reduction of the received signal (*Figure 6-13*). With this method, echoes from the discontinuities are not shown on the CRT. Therefore, depth information on the discontinuities is not determined. Typical discontinuity examples are laminations, corrosion, and cracks.

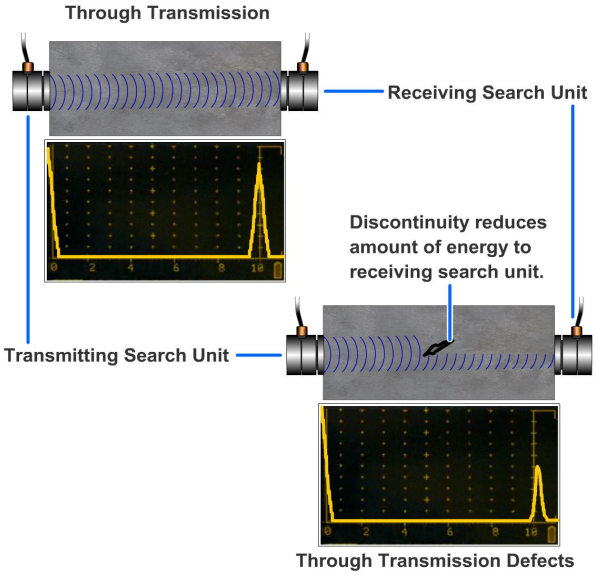


Figure 6-13 — Through-transmission inspection.

ANGLE BEAM — Angle-beam methods are used extensively for field NDI, and can provide for inspection of areas with complex geometry or limited access. This is because angle beams can travel through a material by bouncing from surface to surface. Useful inspection information can be obtained at great distances from the search unit. Angle-beam inspections are particularly applicable to inspections around fastener holes, inspection of cylindrical components, examination of skins for cracks, and inspection of welds. *Figure 6-14* shows typical angle-beam inspections.

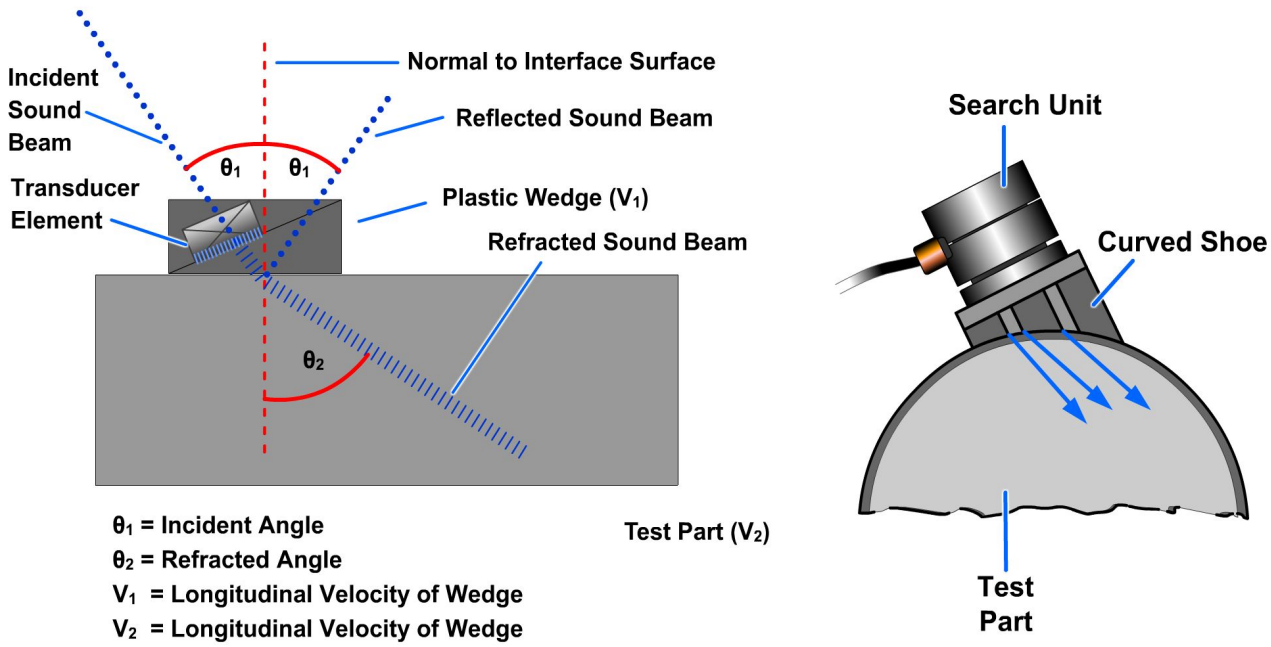


Figure 6-14 — Angle-beam inspection.

SURFACE WAVE — The surface-wave method projects a beam of vibrations that travel along the surface and just below the surface of the material. When surface waves are used to inspect painted surfaces, caution should be exercised during set up and interpretation due to the possibility of surface reflection from scratches and breaks in the painted surface. Surface-wave inspections can be used in many field NDI applications involving surface cracks or slight subsurface discontinuities. On smooth surfaces, sound energy can travel long distances with little energy loss. Surface waves travel around curved corners, and they reflect at sharp edges. Rough surfaces or liquid on the surface attenuate surface waves so the area in front of the search unit must be kept clear of couplant. *Figure 6-15* shows a typical surface-wave inspection.

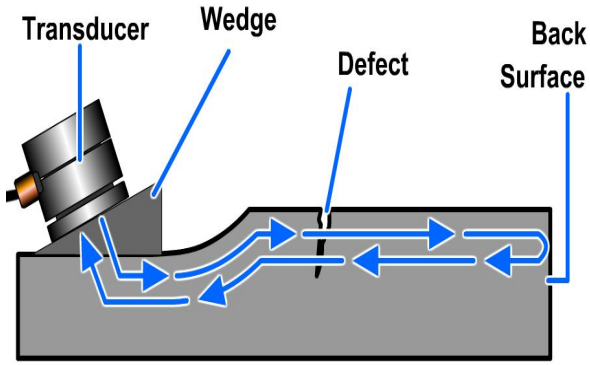


Figure 6-15 — Surface-wave inspection.

Eddy Current Inspection

Eddy currents are electrical currents induced in a conductor of electricity by reaction with a magnetic field. The eddy currents are circular in nature, and their paths are oriented perpendicular to the direction of the applied magnetic field. In general, during eddy current testing, the varying magnetic field(s) is/are generated by an alternating current (ac) flowing through a coil of wire positioned immediately adjacent to the conductor, around the conductor, or within the conductor. *Figure 6-16* shows eddy currents flowing in various configurations.

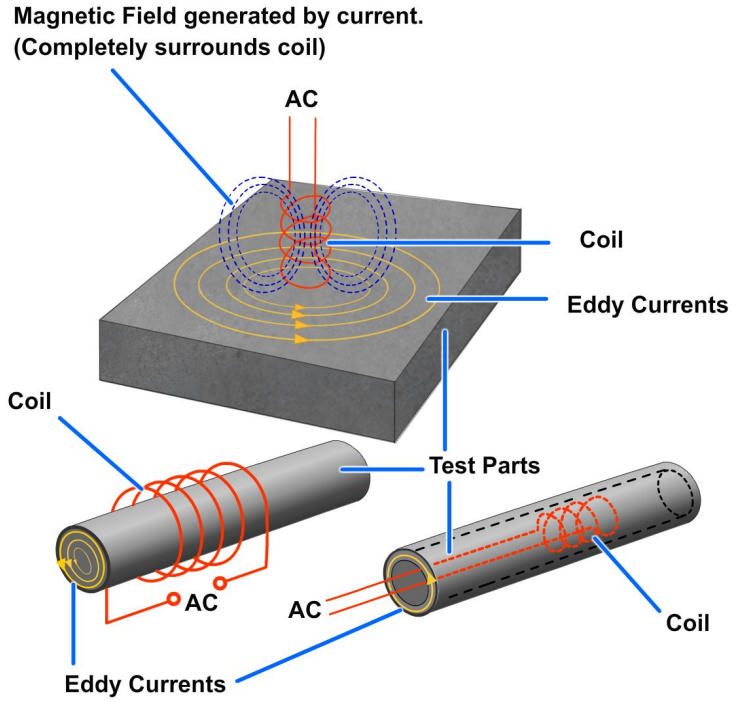


Figure 6-16 — Generation of eddy currents in various part configurations.

COILS AND PROBES — Eddy current coils and probes consist of one or more coils of wire designed to introduce a varying magnetic field into a part to determine the effects of test variables on this magnetic field. Generation of the magnetic field results from an alternating current flowing through the coil. A fundamental consideration in selecting an eddy current probe or test coil is its intended use. A small diameter probe or narrow encircling coil will provide increased resolution of small defects. A larger probe or wider encircling coil will provide better averaging of bulk properties.

TEST COIL CONFIGURATIONS — Eddy current probes and coils can be classified into three types: surface probes, encircling coils, and inside (bobbin-type) coils. *Figure 6-17* shows sketches of the general configuration of each type of coil or probe. *Figure 6-18* shows photographs of typical surface probes used for eddy current testing. Most eddy current testing in the field is concerned with surface coils (probes). The surface probe is used on plates, sheets, and irregular-shaped parts. An inside coil may be used on tubes, pipes, or other parts that are accessible to the inside. The inside coil should nearly fill the part opening in order to provide good test sensitivity. The use of inside coils is restricted by bends or nonuniform diameters. Encircling coils are used primarily for inspecting rods, tubes, cylinders, or wire. With the encircling or inside coils, the entire circumference of the specimen is evaluated at one time. Consequently, the exact location of defects cannot

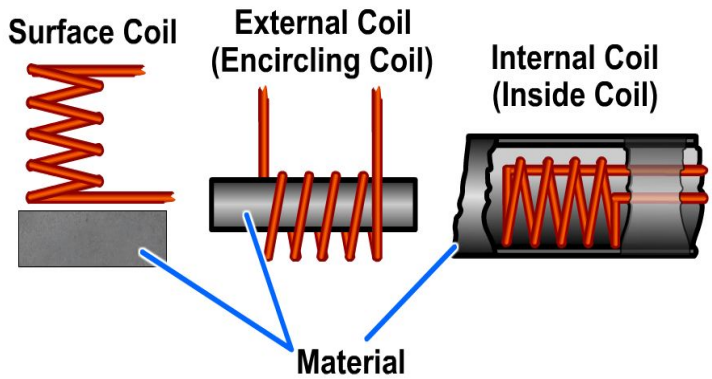


Figure 6-17 — Basic coil configurations.

be defined. The surface coil has the ability to better define the exact location of discontinuities.

Figure 6-18 — Typical eddy current test probes.

Dye Penetrant Inspection

The dye penetrant inspection is a simple, inexpensive, and reliable nondestructive inspection method for detecting discontinuities that are open to the surface of the item to be inspected. It can be used on metals and other nonporous materials that are not attacked by penetrant materials. With the proper technique, it will detect a wide variety of discontinuities, ranging in size from those readily visible down to microscopic level, as long as the discontinuities are open to the surface and are sufficiently free of foreign material. *Figure 6-19* shows the basic principles of the penetrant inspection process. A penetrating liquid, which contains dyes, is applied to the surface of a clean part to be inspected. The penetrant is allowed to remain on the surface of the part for a period of time to permit it to enter and fill any openings or discontinuities. After a suitable dwell period, the penetrant is removed from the part's surface. Care must be exercised to prevent removal of the penetrant that is contained in the discontinuities. A material called "developer" is then applied. The developer aids in drawing any trapped penetrant from the discontinuities and improves the visibility of any indications. For more information concerning the dye penetrant inspection, consult the *Nondestructive Inspection Methods, Basic Theory* NAVAIR 01-1A-16-1, manual.

Figure 6-19 — Basic penetrant process.

WELDING

Welding is the most practical of the many metal-joining processes available to aircraft manufacturers. The welded joint offers rigidity, simplicity, low weight, high strength, and low-cost production equipment. Consequently, welding has been universally adopted in the building of all types of aircraft. Many structural parts, as well as nonstructural parts,

Interaction Available

are joined by some form of welding, and the repair of these many parts is an indispensable part of aircraft maintenance.

QUALIFICATIONS OF WELDERS

For advancement, it is important to be familiar with the operation of welding equipment and materials. An AM should also be able to perform simple welding, brazing, soldering, and cutting operations on ferrous and nonferrous metals.

Only a certified welder can weld on aircraft structural parts. To be certified as an aircraft welder, a qualification test conducted in the presence of a Navy inspector must be passed. Passing this test entitles a welder to a certificate signed by the inspector attesting that the welder is capable of welding the class of material and type of weld indicated on the certificate.

For the benefit of those desiring to qualify as aircraft welders, training programs are available at NADEPs as well as facilities for testing.

RECERTIFICATION OF WELDERS

Only currently certified aeronautical welders may weld on aeronautical equipment. Initial certification is attained by satisfactory completion of Navy training course(s) N-701-0007 and/or N-701-0009, as applicable. Certification can also be obtained by documented satisfactory completion of equivalent training in accordance with *Aeronautical and Support Equipment Welding*, NAVAIR 01-1A-34, manual, and satisfactory completion of recertification testing. If proficiency is maintained, the recertification interval for IMA-level aeronautical equipment welders is one year. Maintaining proficiency requires documented frequency of use, as specified in NAVAIR 01-1A-34. Failure to maintain proficiency in any group(s) of metals will terminate current certification in that/those group(s).

Recertification is normally accomplished by locally producing acceptable test welds and submitting those welds to the nearest authorized welding examination and evaluation facility. Examination and evaluation facilities must complete required testing of test weld specimens and provide test results and recertification documentation, as appropriate, to the affected welder's command within 30 days of the test weld(s) receipt.

Detailed procedures for obtaining test plates, production and submission of test welds, and documentation are contained in *Aeronautical and Support Equipment Welding,* NA 01-1A-34, manual. The TYCOMs/ACCs may extend current certification of welders for a maximum of 90 days in cases where test welds have been submitted but results and recertification documentation have not been received from the cognizant examination and evaluation facility. Welders whose test specimens fail to meet minimum requirements are allowed one retest. This retest will require submission of a double set of test welds of the failed group(s) of metal(s) to the same examination and evaluation facility that failed the test welds first submitted. Welding examination and evaluation facilities will forward double sets of test plates to the failed welder's command concurrently with the notification of failure. Retest test welds must be completed and submitted within 30 days of receipt of notification of failure of first test weld(s). Failure of any retest test welds to meet minimum requirements will require the welder to satisfactorily complete the Navy training courses N-701-0008/N-701-0010, as applicable, to recertify.

Aeronautical equipment welders may weld only on equipment, components, and items manufactured from the group of metals for which they are currently certified and for

which weld repairs are authorized by applicable technical publications or directives. Groups of metals for which separate and distinct certification is required are specified in NA 01-1A-34. Separate certification is also required for oxyfuel brazing process.

The NA 01-1A-34 manual contains additional information and guidance relative to qualification, certification/recertification, and employment of aeronautical equipment welders. It is, however, a general series technical manual intended to be used in conjunction with the COMNAVAIRFORINST 4790.2 and with specific maintenance/repair/overhaul manuals/engineering documents. In cases of conflict between NA 01-1A-34 and the COMNAVAIRFORINST 4790.2 regarding certification/recertification policy, the COMNAVAIRFORINST 4790.2 takes precedence.

The QA/A is responsible for monitoring aeronautical equipment welder certification/recertification. The COMNAVAIRFORINST 4790.2 should be consulted for specifics. A Welding Certificate (Operator's Card), DD Form 2758, will be issued for each material category in which the welder is qualified. The welding certificate will be filled out, dated, and signed by an authorized representative of an examination facility. *Figure 6-20* provides a sample of the welding certificate. *Figures 6-21* and *6-22* show a sample Welding Examination Record (DD Form 2757) and instructions.

WELDING CERTIFICATION CARD

NAME _____ WELDER IDENTIFICATION NO. _____

is certified in accordance with NA 01-1A-34/TO 00-25-252/TC 9-238/ AWS B2.1 for the welding processes, metal groups, thicknesses and positions that are listed and initialed/stamped on the back of this card.

DATE _____ AUTHORIZED ENG. LAB SIGNATURE _____

DATE _____ WELD INSTRUCTOR/INSPECTOR SIGNATURE _____

CERTIFYING ACTIVITY _____

PROCESS	METAL GROUP	THICKNESS LIMITATIONS	POSITIONS	INITIAL/ STAMP	EXP. DATE

Figure 6-20 — Welding Certification (DD Form 2758).

WELDING EXAMINATION RECORD			1. DATE
SECTION I - APPLICATION			
2. NAME *(Last, First, Middle Initial)*		3. PARENT ORGANIZATION	4. UNIT ADDRESS
5. QUALIFICATION GROUP	6. RATING/RATE	7. WELDER IDENTIFICATION NUMBER	8. EXPIRATION DATE
9. WELDING SCHOOL OR SOURCE OF TRAINING		10. WELDING PROCESS	

11. WELDING PROCEDURE SPECIFICATIONS *(See Table 3-3 for all parameters. Use a. - n. for special qualifications)*	WPS NUMBERS								
a. BASE METAL									
b. FILLER METAL TYPE									
c. FILLER METAL DIAMETER									
d. POSITION									
e. TORCH SHIELDING GAS TYPE									
f. TORCH SHIELDING GAS FLOW									
g. ROOT SHIELDING GAS TYPE									
h. ROOT SHIELDING GAS FLOW									
i. NOZZLE SIZE									
j. CURRENT TYPE									
k. AMPERAGE									
l. ELECTRODE TYPE									
m. ELECTRODE DIAMETER									
n. NUMBER OF PASSES									

12. SIGNATURE OF APPLICANT	13. SIGNATURE OF OBSERVING OFFICIAL. I certify the weld specimen was completed by the applicant using the above procedure.

SECTION II - EXAMINATION RESULTS

WPS NUMBERS	TEST SPECIMEN				RETEST SPECIMEN			
	14. VISUAL	15. RADIOGRAPHIC	16. BEND	17. METALLOGRAPHIC	14. VISUAL	15. RADIOGRAPHIC	16. BEND	17. METALLOGRAPHIC

18. REMARKS

19. TO OBTAIN REQUALIFICATION OPERATOR MUST:

☐ RESUBMIT EXAMINATION ☐ ATTEND AUTHORIZED WELDING TRAINING SCHOOL

20. TESTING OFFICIAL		a. SIGNATURE	
☐ QUALIFIED	☐ NOT QUALIFIED		
b. ORGANIZATION AND ADDRESS		c. QUALIFICATION GROUP	d. LEVEL *(AF only)*
21a. SIGNATURE OF CERTIFYING OFFICIAL			b. DATE CERTIFIED

Figure 6-21 — Welding Examination Record (DD Form 2757) (front).

INSTRUCTIONS FOR COMPLETION OF DD FORM 2757.
WELDING EXAMINATION RECORD

SECTION I:

Block 2 - NAME. Self-explanatory.

Block 3 - PARENT ORGANIZATION. Self-explanatory.

Block 4 - UNIT ADDRESS. Self-explanatory.

Block 5 - QUALIFICATION GROUP. Metal groups submitted for certification.

Block 6 - RATING/RATE. Enter military rank or civilian pay number.

Block 7 - WELDER IDENTIFICATION NUMBER. Enter military identification number or civilian pay number.

Block 9 - WELDING SCHOOL OR SOURCE OF TRAINING. Self-explanatory.

Block 10 - WELDING PROCESS. Process used to accomplish the weld.

Block 11 - WELDING PROCEDURE USED. Conditions used in completing test welds will be listed under appropriate WPS number column (See Table 3-3).

Block 12 - SIGNATURE OF APPLICANT. Self-explanatory.

Block 13 - SIGNATURE OF OBSERVING OFFICIAL. Signature of the person observing the certification welding.

SECTION II:

Blocks 14 - 17. The appropriate blocks will be marked either satisfactory (SAT) or unsatisfactory (UNSAT) in accordance with the results of the particular examination.

Block 18 - REMARKS. Record cause of any unsatisfactory results or other relevant information.

Block 19 - TO OBTAIN REQUALIFICATION OPERATOR MUST. Decision made by evaluating activity after failure of previous test specimens.

Block 20 - TESTING OFFICIAL. Annotate whether qualified or not qualified in appropriate box (All DOD). Signature of the official who evaluates the test specimens. Organization and address of testing official.

Block 21 - CERTIFYING OFFICIAL. The welding instructor/inspector who actually certifies the welder at the evaluation laboratory will enter signature and record the effective date of certification.

Figure 6-22 — Welding Examination Record (DD Form 2757) (back).

OXYACETYLENE WELDING

Oxyacetylene welding is a gas welding process. A coalescence or bond is produced by heating with a gas flame or flames obtained from the combustion of acetylene with oxygen, with or without the application of pressure, and with or without the use of filler metal. A welding torch is used to mix the gases in the proper proportions and to direct the flame against the parts to be welded. The molten edges of the parts then literally flow together and, after cooling, form one solid piece. Usually, it is necessary to add extra material to the joint. The correct material in rod form is dipped in and fuses with the puddle of molten metal from the parent metal parts.

Acetylene is widely used as the combustible gas because of its high flame temperature when mixed with oxygen. The temperature, which ranges from approximately 5700° to 6300°F, is so far above the melting point of all commercial metals that it provides a means for the rapid, localized melting essential in welding. The oxyacetylene flame is also used in cutting ferrous metals. The oxyacetylene welding and cutting methods are widely used by all types of maintenance activities because the flame is easy to regulate, the gases may be produced inexpensively, and the equipment can be transported easily and safely.

Oxyacetylene Welding Equipment

The equipment used for oxyacetylene welding consists of a source of oxygen and a source of acetylene from a portable or stationary outfit. The portable outfit consists of an oxygen cylinder and an acetylene cylinder with attached valves, regulators, gauges, and hoses (*Figure 6-23*). This equipment may be temporarily secured on the floor or mounted on a two-wheel, welded, steel truck equipped with a platform that will support two large size cylinders. The cylinders are secured by chains attached to the truck frame. A metal toolbox, welded to the frame, provides storage for torches, tips, gloves, fluxes, goggles, and necessary wrenches.

Stationary equipment is installed where welding operations are conducted in a fixed location. The acetylene and oxygen are piped to several welding stations from a central supply. Master regulators are used to control the flow of gas and maintain a constant pressure at each station.

OXYGEN —Oxygen is a colorless, tasteless, odorless gas that is slightly heavier than air. Oxygen is nonflammable, but it will support combustion when combined with other gases. This means that it aids in burning, and this burning gives off considerable heat and light. In its free state, oxygen is one of the most common elements. The atmosphere is made up of

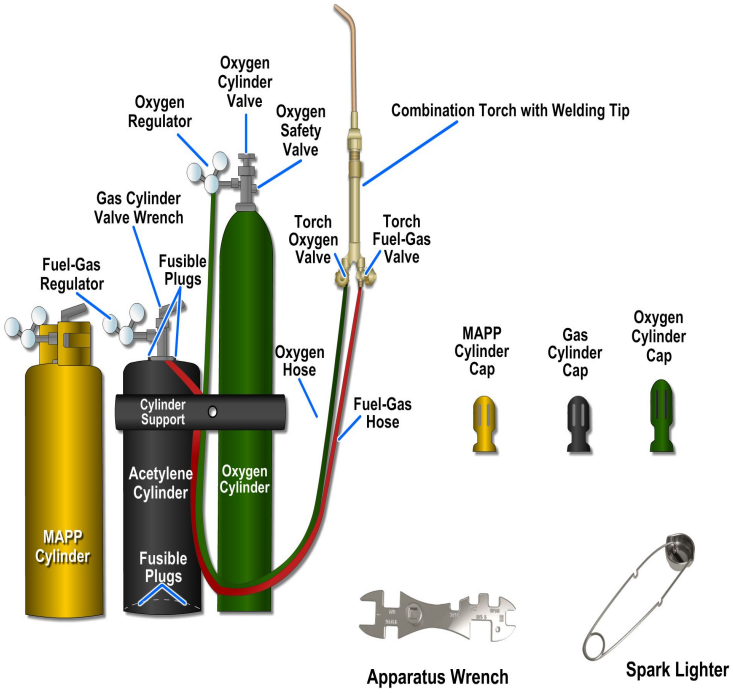


Figure 6-23 — Portable oxyacetylene welding and cutting equipment.

approximately 21 parts of oxygen and 78 parts of nitrogen, with the remainder being rare gases. It is the presence of oxygen in the air that causes rusting of ferrous metals, the discoloration of copper, and corrosion of aluminum. This action is known as oxidation.

Oxygen is obtained commercially either by the liquid air process or by the electrolytic process. In the liquid air process, air is compressed and cooled to a point where the gases become a liquid. As the temperature of the liquid air is raised, nitrogen in a gaseous form is given off first, since its boiling point is lower than that of liquid oxygen.

These gases, having been separated, are further purified and compressed into cylinders for use.

In the electrolytic process, water is broken down into hydrogen and oxygen by the passage of an electric current through it. The oxygen collects at the positive terminal and the hydrogen at the negative terminal. Each of the gases is then collected and compressed into cylinders for use.

OXYGEN CYLINDERS — A typical oxygen cylinder (*Figure 6-24*) is made of steel and has a capacity of 220 cubic feet at a pressure of 2,000 psi and a temperature of 70°F. Each oxygen cylinder has a high-pressure outlet valve located at the top of the cylinder, a removable metal cap for the protection of the outlet valve during shipment or storage, and a low melting point safety fuse plug and disk. All oxygen cylinders are painted green for identification.

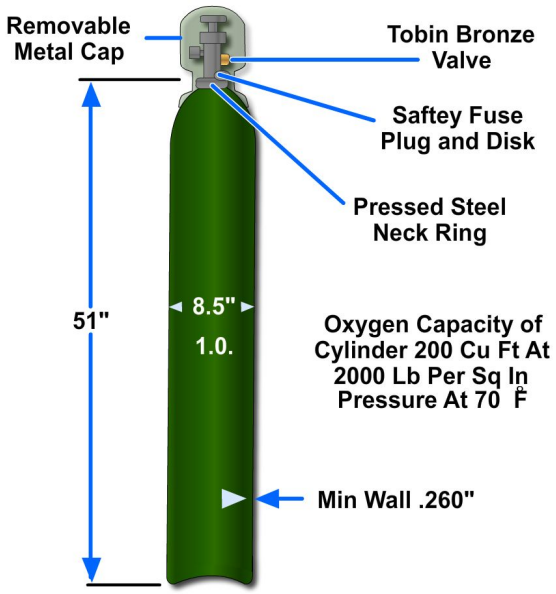


Figure 6-24 — Typical oxygen cylinder.

Technical oxygen cylinders are solid green, while breathing oxygen cylinders are green with a white band around the top.

> ⚠ **CAUTION** ⚠
>
> Oxygen should never be brought in contact with oil or grease. In the presence of pure oxygen, these substances become highly combustible. Oxygen hose and valve fittings should never be oiled or greased or handled with oily or greasy hands. Even grease spots on clothing may flare up or explode if struck by a stream of oxygen.

PRESSURE REGULATORS —The gases compressed in oxygen and acetylene cylinders are at pressures too high for oxyacetylene welding. Regulators are necessary to reduce pressure and control the flow of gases from the cylinders. Most regulators in use are either the single-stage or the two-stage type. Single-stage regulators reduce the pressure of the gas in one step; two-stage regulators do the same job in two steps or stages. Generally, less adjustment is necessary when two-stage regulators are used.

Figure 6-25 shows a typical single-stage regulator. The regulator mechanism consists of a nozzle through which the high-pressure gases pass, a valve seat to close off the nozzle, and balancing springs. These are all enclosed in a suitable housing. Pressure gauges are provided to indicate the pressure in the cylinder or pipeline (inlet), as well as the working pressure (outlet). The inlet pressure gauge, used to record cylinder pressures, is a high-pressure gauge and is graduated from 0 to 3,000 psi. The outlet pressure gauge, used to record working pressures, is a low-pressure gauge and is graduated from 0 to 500 psi.

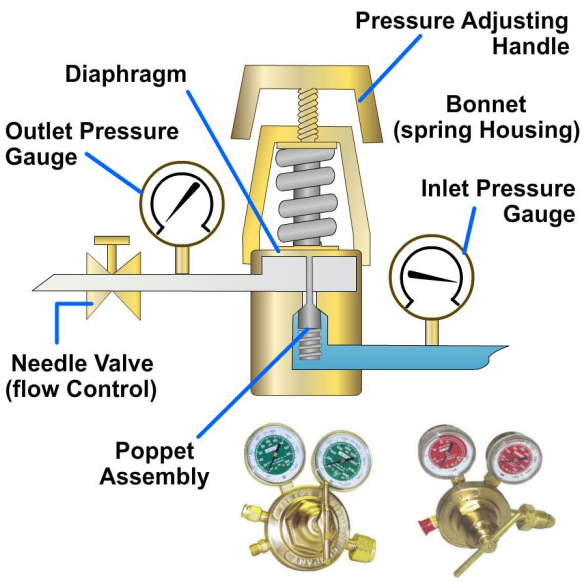


Figure 6-25 —Single-stage oxygen regulator.

In the oxygen regulator, the oxygen enters through the high-pressure inlet connection and passes through a glass wool filter that removes dust and dirt. The adjusting screw is turned in and to the right to allow the oxygen to pass from the high-pressure chamber to the low-pressure chamber of the regulator, through the regulator outlet, and through the hose to the torch at the pressure shown on the working pressure gauge. Changes in this pressure may be made at will, simply by adjusting the handle until the desired pressure is registered. Turning the adjusting screw to the right INCREASES the working pressure; turning it to the left DECREASES the working pressure.

The operation of the two-stage regulator is similar in principle to the single-stage regulator. The difference is that the total pressure decrease takes place in two steps instead of one. On the high-pressure side, the pressure is reduced from cylinder pressure to intermediate pressure. On the low-pressure side, the pressure is reduced from intermediate pressure to working pressure. Because of the two-stage pressure control, the working pressure is held constant, and pressure adjustment during welding operations is not required. A two-stage regulator is shown in *Figure 6-26*.

The acetylene regulator controls and reduces the acetylene pressure from any standard cylinder that contains pressures up to 500 psi. It is of the same general design as the oxygen regulator, but it will not withstand such high pressures. The high-pressure gauge, on the inlet side of the regulator, is graduated from 0 to 500 psi. The low-pressure gauge, on the outlet side of the regulator, is graduated from 0 to 30 psi. Acetylene should not be used at pressures exceeding 15 psi.

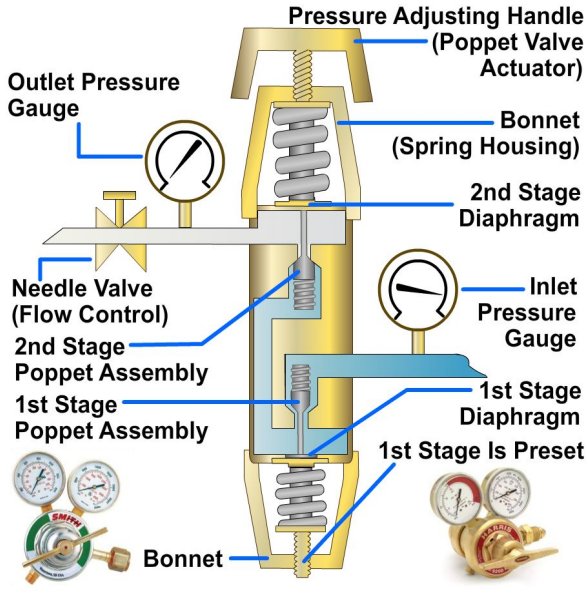


Figure 6-26 — Two-stage regulator.

ACETYLENE —Acetylene is a fuel gas made up of carbon and hydrogen. It is manufactured

Interaction Available
Interaction Available

by the chemical reaction between calcium carbide—a gray stone like substance—and water in a generating unit. Acetylene is colorless, but it has a distinctive odor that can be easily detected.

Mixtures of acetylene and air that contain from 2 to 80 percent of acetylene by volume will explode when ignited. However, with suitable welding equipment and proper precautions, acetylene can be safely burned with oxygen for welding and cutting purposes. When burned with oxygen, acetylene produces a very hot flame that has a temperature between 5700° and 6300°F.

ACETYLENE CYLINDERS —Acetylene stored in a free state under pressure greater than 15 psi can be broken down by heat or shock, and possibly explode. Under pressure of 29.4 psi, acetylene becomes self-explosive, and a slight shock will cause it to explode spontaneously. However, when dissolved in acetone, it can be compressed into cylinders at pressures up to 250 psi.

The acetylene cylinder (*Figure 6-27*) is filled with porous materials, such as balsa wood, charcoal, and shredded asbestos, to decrease the size of the open spaces in the cylinder. Acetone, a colorless, flammable liquid, is added until about 40 percent of the porous material is filled. The filler acts as a large sponge to absorb the acetone, which, in turn, absorbs the acetylene. In this process, the volume of the acetone increases as it absorbs the acetylene, while acetylene, being a gas, decreases in volume. The acetylene cylinders are equipped with safety plugs, which have a small hole through the center. This hole is filled with a metal alloy, which melts at approximately 212°F or releases at 500 psi. When a cylinder is overheated, the plug will melt and permit the acetylene to escape before a dangerous pressure can build up. The plughole is too small to permit a flame to burn back into the cylinder if the escaping acetylene should become ignited.

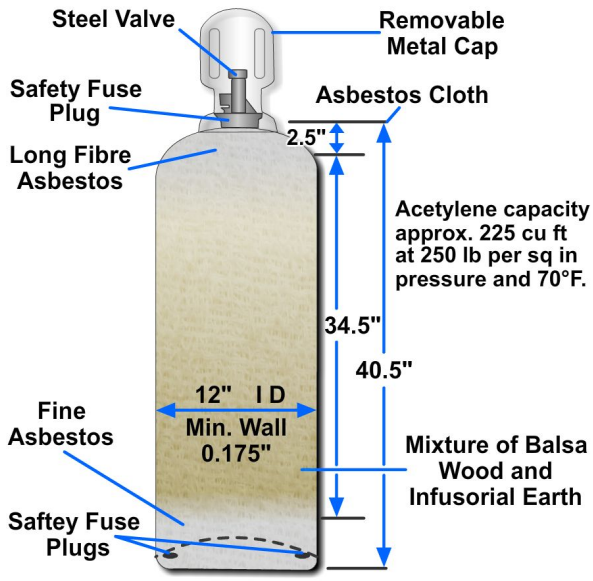


Figure 6-27 — Acetylene cylinder.

WELDING TORCHES —The oxyacetylene welding torch is used to mix oxygen and acetylene gas in the proper proportions, and to control the volume of these gases burned at the welding tip. The torch has two needle valves, one for adjusting the flow of acetylene and the other for adjusting the flow of oxygen. In addition, there are two tubes, one for oxygen and the other for acetylene; a mixing head; inlet nipples for the attachment of hoses; a tip; and a handle. The tubes and handle are made of seamless hard brass, copper-nickel alloy, stainless steel, or other noncorrosive metals of adequate strength.

There are two types of welding torches—the low-pressure or injector type and the equal-pressure type. In the low-pressure or injector type (*Figure 6-28*), the acetylene pressure is less than 1 psi. A jet of high-

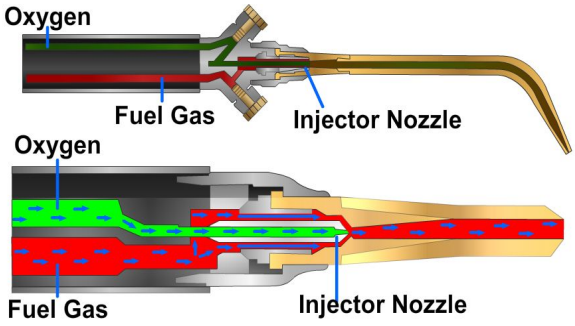


Figure 6-28 — Mixing head for injector-type welding torch.

pressure oxygen is used to produce a suction effect to draw in the required amount of acetylene. This is accomplished by the design of the mixer in the torch, which operates on the injector principle. The welding tips may or may not have separate injectors designed integrally with each tip.

The equal pressure torch (*Figure 6-29*) is designed to operate with equal pressures for the oxygen and acetylene. The pressure ranges from 1 to 15 psi. This torch has certain advantages over the low-pressure type because the flame can be more readily adjusted, and since equal pressures are used for each gas, the torch is less susceptible to flashbacks.

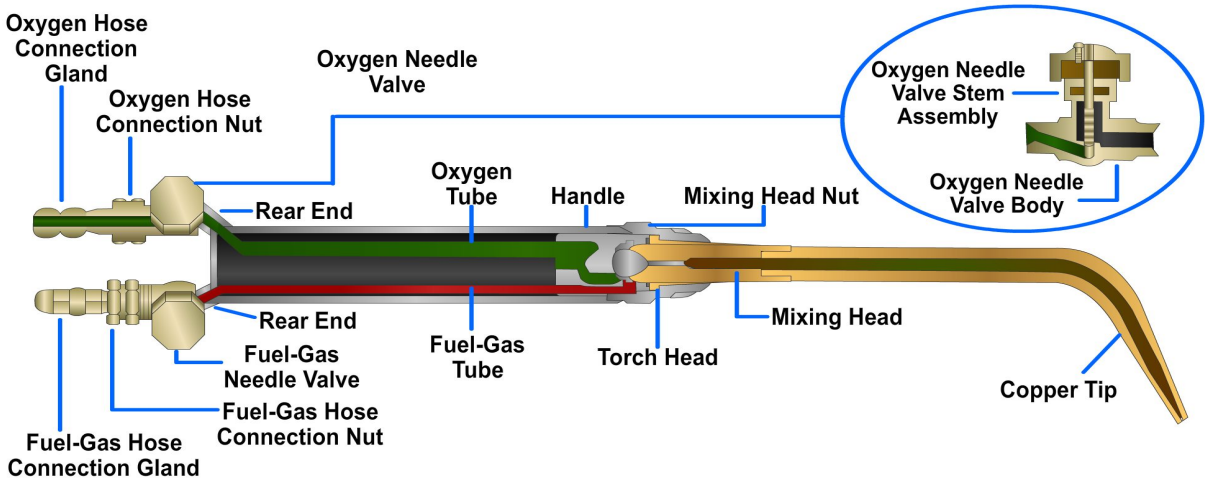


Figure 6-29 — Equal pressure welding torch.

The welding tips are made of hard, drawn, electrolytic copper or 95-percent copper and 5-percent tellurium. They are made in various styles and types, some having a one-piece tip either with a single orifice or a number of orifices, and others with two or more tips attached to one mixing head. The diameters of the tip orifices differ to control the quantity of heat and the type of flame. These tip sizes are designated by numbers that are arranged according to the individual manufacturer's system. In general, the smaller the number, the smaller the tip orifice.

No matter what type or size tip selected, the tip must be kept clean. Quite often the orifice becomes clogged with slag. When this happens, the flame will not burn properly. The tip should be inspected before use. If the passage is obstructed, it can be cleared with wire tip cleaners of the proper diameter, or with soft copper wire. Tips should not be cleaned with machinist's drills or other sharp instruments. These devices may enlarge or scratch the tip opening and greatly reduce the efficiency of the torch tip.

HOSE — The hose used to make the connection between the torch and the regulators is strong, nonporous, light, and flexible to make the torch movements easy. It is made to withstand high internal pressures, and the rubber used in its manufacture is chemically treated to remove sulfur to avoid the danger of spontaneous combustion.

The oxygen hose is GREEN, and the acetylene hose is RED. The hose is a rubber tube with braided or wrapped cotton or rayon reinforcements and a rubber covering. The hoses have connections at each end so they can be connected to their respective regulator outlet and torch inlet connections. To prevent a dangerous interchange of acetylene and oxygen hoses, all threaded fittings used for the acetylene hookup are left-handed threads, and all threaded fittings for oxygen hookup are right-handed threads. The hoses are obtainable as a single hose for each gas or with the hoses bonded

together along their length under a common outer rubber jacket. This type prevents the hose from kinking or becoming entangled during the welding operation.

LIGHTERS — A flint lighter is provided for igniting the torch. The lighter consist of a file-shaped piece of steel, usually recessed in a cuplike device, and a piece of flint that can be drawn across the steel, which produces the sparks required to light the torch.

WARNING

Matches should never be used to ignite a torch; their length requires bringing the hand too close to the tip to ignite the gas. Accumulated gas may envelope the hand, and, when ignited, causes a severe burn.

GOGGLES — Welding goggles are fitted with colored lenses to keep out heat and light rays and to protect the eyes from sparks and molten metal. Regardless of the shade of lens used, goggles should be protected by a clear glass cover. The welding operator should select the shade or density of color that is best suited for his/her particular work. The desired lens is the darkest shade that will show a clear definition of the work without eyestrain. Goggles should fit closely around the eyes, and should be worn at all times during welding and cutting operations. Special goggles, using standard lenses, are available for use with spectacles.

WELDING (FILLER) RODS — The use of the proper type of filler rod is very important in oxyacetylene welding operations. This material not only adds reinforcement to the weld area, but also adds desired properties to the finished weld. By selecting the proper type of rod, either tensile strength or ductility can be secured in a weld. Similarly, rods can be selected that will help retain the desired amount of corrosion resistance. In some cases, a suitable rod with a lower melting point will eliminate possible cracks from expansion and contraction.

Welding rods are classified as ferrous and nonferrous. The ferrous rods include carbon and alloy steel rods as well as cast iron rods. Nonferrous rods include brazing and bronze rods, aluminum and aluminum alloy rods, magnesium and magnesium alloy rods, copper rods, and silver rods. The diameter of the rod used is governed by the thickness of the metals being joined. If the rod is too small, it will not conduct heat away from the puddle rapidly enough, and a burned weld will result. A rod that is too large will chill the puddle. As in selecting the proper size welding torch tip, experience will enable the welder to select the proper diameter welding rod.

Welding Flames

The welding flame is classified as neutral, carburizing, or oxidizing. Each type of flame has its own special function. The operator can adjust the torch to produce the type of flame best suited for the job at hand.

The neutral flame, in which a balanced mixture of oxygen and acetylene is burned, is used for most welding operations. The carburizing flame, in which an excess of acetylene is burned, is used when welding nickel alloys. The oxidizing flame, in which an excess of oxygen is burned, is used for welding bronze or fusing brass and bronze.

NEUTRAL FLAME — The neutral flame does not alter the composition of the base metal to any great extent; therefore, it is the flame best suited for most metals. The neutral flame burns at approximately 5850°F. A balanced mixture of one volume of oxygen and one volume of acetylene is supplied from the torch when the flame is adjusted to neutral.

The neutral flame is divided into two distinct zones. The inner zone consists of a white, clearly defined, round, smooth cone, 1/16 to 3/4 inch in length. The outer zone, made up of completely burned oxygen and acetylene, is blue with a purple tinge at the point and edges.

A neutral flame melts metal without changing its properties, and it leaves the metal clear and clean. If the mixture of oxygen and acetylene is correct, the neutral flame allows the molten metal to flow smoothly, and few sparks are produced when welding most metals.

CARBURIZING FLAME — The carburizing flame, produced by burning an excess of acetylene, may be recognized by its three distinct colors. There is a bluish-white inner cone, a white intermediate cone, and a light-blue outer flame. It may be recognized also by the feather at the tip of the inner cone. The degree of carburization can be judged by the length of the feather.

OXIDIZING FLAME — The oxidizing flame is produced by burning an excess of oxygen. It has the general appearance of the neutral flame, but the inner cone is shorter, slightly pointed, and has a purplish tinge. This flame burns with a hissing sound. When welding ferrous metals, an oxidizing flame is recognized by the numerous sparks that are thrown off as the metal melts and by the foam that forms on the surface.

FLAME ADJUSTMENT — To adjust the flame, the torch should be lit by opening the torch acetylene valve one-fourth to one-half turn. With only the acetylene valve open, the flame will be yellow in color and give off smoke and soot.

The torch oxygen valve should now be opened slowly. The flame will gradually change in color from yellow to blue, and it will show the characteristics of the excess acetylene flame described earlier.

With most torches, there will be a slight excess of acetylene when the oxygen and acetylene valves are wide open and the recommended pressures are being used. The acetylene valve should now be closed slowly. The secondary cone will get smaller until it finally disappears completely. Just at this point of complete disappearance, the neutral flame is formed.

By closing the acetylene valve still further, the effect of an excess of oxygen can be seen. A change will be noted, although it is by no means as sharply defined as that between the neutral and excess acetylene flames. The entire flame will decrease in size, and the inner cone will become much less sharply defined.

Because of the difficulty in making a distinction between the excess oxygen and neutral flames, an adjustment of the flame to neutral should always be made from the excess acetylene side. The flame should always be adjusted first so that it shows the secondary cone characteristic of excess acetylene; then, the flow of oxygen increased until this secondary cone just disappears.

During actual welding operations, where a neutral flame is essential, the flame should be checked occasionally to make certain it is neutral. This is accomplished by momentarily withdrawing the torch from the work and increasing the amount of acetylene until a distinctive feathery edge appears on the inner cone. Then, the amount

of acetylene should be decreased slowly until a well-defined cone, characteristic of the neutral flame, is formed.

With each size of tip, a neutral, oxidizing, or carburizing flame can be obtained. It is also possible to obtain a "harsh" or "soft" flame by increasing or decreasing the pressure of both gases.

For most regulator settings, the gases are expelled from the torch tip at a relatively high velocity, and the flame is called "harsh." For some work it is desirable to have a "soft" or low-velocity flame without a reduction in thermal output. This may be achieved by using a larger tip and closing the needle valves until the neutral flame is quiet and steady. It is especially desirable to use a soft flame when welding aluminum, to avoid blowing holes in the metal when the puddle is formed.

BACKFIRE AND FLASHBACK — Improper handling of the torch may cause the flame to backfire or, in very rare cases, to flashback. A backfire is a momentary backward flow of the gases at the torch tip, causing the flame to go out. Sometimes the flame may immediately come on again, but a backfire is always accompanied by a snapping or popping noise. A backfire may be caused by touching the tip against the work, by overheating the tip, by operating the torch at other than recommended pressures, by a loose tip or head, or by dirt or slag in the end of the tip. A backfire is rarely dangerous, but the molten metal may be splattered when the flame pops.

A flashback is the burning of the gases within the torch, and it is dangerous. It is usually caused by loose connections, improper pressures, or overheating of the torch. A shrill hissing or squealing noise accompanies a flashback; and unless the gases are turned off immediately, the flame may burn back through the hose and regulators and cause great damage. The cause of a flashback should always be determined, and the trouble remedied before relighting the torch.

Fundamental Welding Techniques

The composition, thickness, shape, and position of the metal to be welded govern the techniques to be used. The fundamental techniques include holding the torch, forehand welding, and backhand welding.

Figure 6-30 — Welding light gauge metals.

Figure 6-31 — Welding heavy plate.

HOLDING THE TORCH — The proper method to use in holding the torch depends upon the thickness of the metal being welded. For light gauge metal, hold the torch as shown in *Figure 6-30*, with the hose draped over the wrist. For heavier work, hold the torch as shown in *Figure 6-31*.

Hold the torch so that the tip is in line with the joint to be welded, and inclined between 30° and 60° from the perpendicular. The exact angle depends upon the type of weld to be made, the amount of preheating necessary, and the thickness and type of metal. The thicker the metal, the more vertical the torch must be for proper heat penetration. The white cone of the flame should be held about 1/8 inch from the surface of the base metal.

If the torch is held in the correct position, a small puddle of molten metal will form. The puddle should be composed of equal parts of the two pieces being welded. After the puddle appears, begin the movement of the tip in a semicircular or circular motion. This movement assures an even distribution of heat on both pieces of metal. The speed and motion of the torch are learned only by practice and experience.

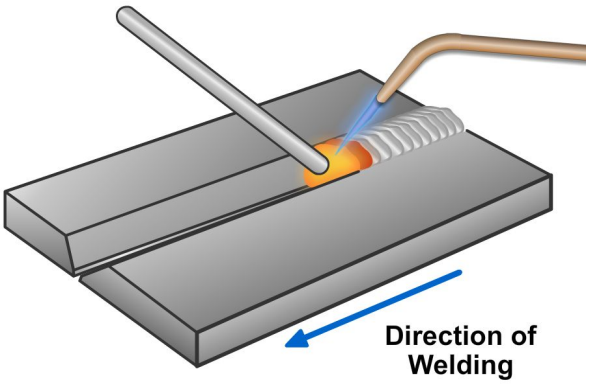


Figure 6-32 — Forehand welding.

FOREHAND WELDING — Forehand (also called "puddle welding" or "ripple welding") is the oldest method of welding. The rod is kept ahead of the tip in the direction in which the weld is being made. The flame should be pointed in the direction of the weld, and the tip held at an angle of about 45° to 60° to the plates (*Figure 6-32*). This position of the flame preheats the edges being welded just ahead of the molten puddle. By moving the tip and welding rod back and forth in opposite semicircular paths, the head is balanced to melt the end of the rod and the sidewalls of the joint into a uniformly distributed molten puddle. As the flame passes the rod, it melts off a short length of the rod and adds it to the puddle. The motion of the torch distributes the molten metal evenly to both edges of the joint and to the molten puddle. This method is used in welding most of the lighter tubing and sheet metals up to 1/8 inch thick because it permits better control of a small puddle and results in a smoother weld. However, the forehand technique is not the best method for welding heavy metals.

BACKHAND WELDING — In this method the torch tip precedes the rod in the direction of welding, and the flame is pointed back at the molten puddle and the completed weld. The end of the rod is placed between the torch tip and the molten puddle. The welding tip should make an angle of about 45° to 60°

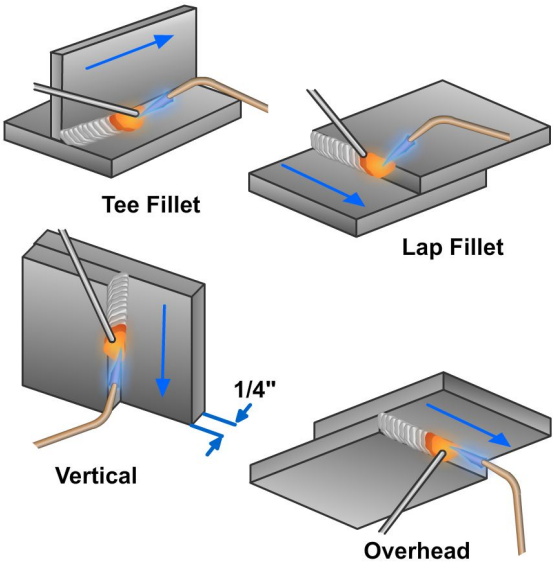


Figure 6-33 — Backhand welding.

with the plates or joint being welded (*Figure 6-33*).

Less motion is required in the backhand method than in the forehand method. If using a straight welding rod, it should be rotated so that the end will roll from side to side and melt off evenly. The rod may also be bent and, when welding, the rod and torch moved back and forth at a rapid rate. If a large weld is being made, the rod should be moved so as to make complete circles in the molten puddle. The torch is moved back and forth across the weld while it is advanced slowly and uniformly in the direction of the weld. The backhand method is usually best found for welding material more than 1/8 inch thick. A narrower "V" can be used at the joint than is possible in forehand welding. An included angle of 60° is a sufficient angle of bevel to get a good joint. It doesn't take as much welding rod or puddling for the backhand method as it does for the forehand method.

By using the backhand technique on heavier material, it is possible to obtain increased welding speeds, better control of the larger puddle, and more complete fusion at the root of the weld. Further, by using a reducing flame with the backhand technique, a smaller amount of base metal is melted while welding a joint. Backhand welding is seldom used on sheet metal because the increased heat generated in this method is likely to cause overheating and burning. When welding steel with a backhand technique and a reducing flame, the absorption of carbon by a thin surface layer of metal reduces the melting point of the steel. This speeds up the welding operation.

WELDING POSITIONS — The four basic welding positions are shown in *Figure 6-34*. Also shown are four commonly used joints. The corner joint and butt joint are classified as groove welds, while the tee and lap joints are classified as fillet welds.

Welding is always done in the flat position whenever possible. The puddle is much easier to control, and the welder can work longer periods without tiring. Quite often it is necessary to weld in the overhead, vertical, or horizontal position in equipment repair.

The flat position is used when the material is to be laid flat or almost flat and welded on the topside. The welding torch is pointed downward toward the work. This weld may be made by either the forehand or backhand technique.

The overhead position is used when the material is to be welded on the underside, with the torch pointed upward toward the work. In welding overhead, the puddle can be kept from sagging if it is not permitted to get too large or assume the form of a large drop. The rod is used to control the molten puddle. The volume of flame should never be permitted to exceed that required to obtain a good fusion of the base metal with the filler rod. Less heat is

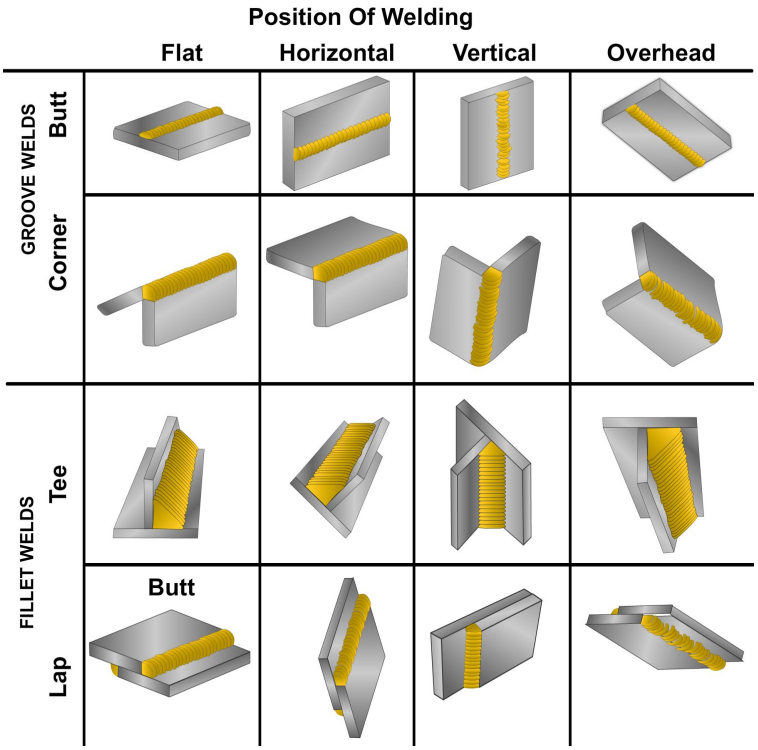


Figure 6-34 — Four basic welding positions.

required in an overhead weld because the heat naturally rises.

The horizontal position is used when the line of the weld runs horizontal across a piece of work, and the torch is directed at the material in a horizontal or near horizontal position. The weld is made from right to left across the plate (for the right-hand welder). The flame is inclined upward at an angle of 45° to 60° and the weld is made with a normal forehand technique. Adding the rod to the top of the puddle will prevent the molten metal from sagging to the lower edge of the bead. If the puddle is to have the greatest possible cohesion, it should not be allowed to get too hot.

In a vertical weld, the pressure exerted by the torch flame must be relied upon to a great extent to support the puddle. It is important to keep the puddle from becoming too hot, and to prevent the hot metal from running out of the puddle onto the finished weld. It may be necessary to remove the flame from the puddle for an instant to prevent overheating, and then return it to the puddle. Vertical welds are begun at the bottom, and the puddle is carried upward with a forehand motion. The tip should be inclined from 45° to 60°, the exact angle depending upon the desired balance between correct penetration and control of the puddle. The rod is added from the top and in front of the flame with a normal forehand technique.

Welded Joints

The properties of a welded joint depend partly on the correct preparation of the edges being welded. All mill scale, rust, oxides, and other impurities must be removed from the joint edges or surfaces to prevent their inclusion in the weld metal. The edges should be prepared to permit fusion without excessive melting, and care should be taken to keep heat loss to a minimum due to radiation into the base metal from the weld. A properly prepared joint will give a minimum of expansion on heating and a minimum of contraction on cooling.

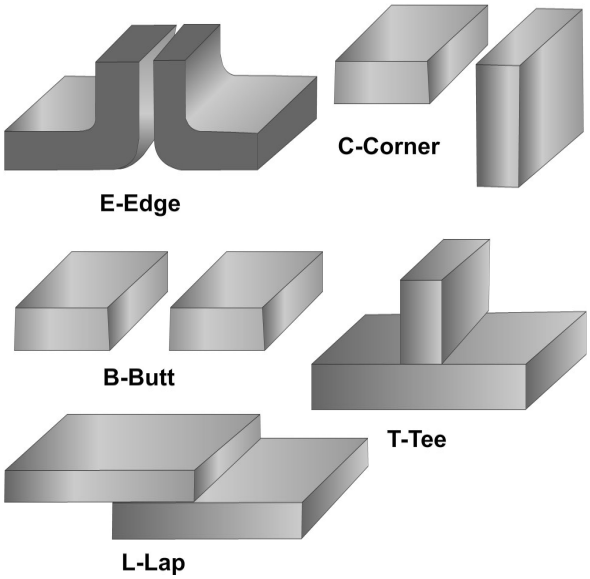


Figure 6-35 — Types of welded joints.

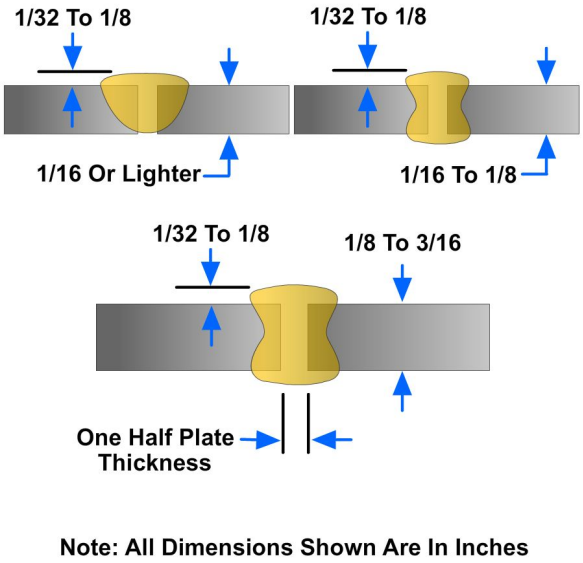


Figure 6-36 — Butt joints in light sections.

The preparation of the metal for welding is governed by the form, thickness, kind of metal, the load that the weld will be required to support, and the available means for preparing the edges to be joined.

The five basic types of welded joints are the butt, tee, lap, edge, and corner. (See *Figure 6-35*.)

BUTT JOINTS —A butt joint is made by placing two pieces of material edge to edge so there is no overlapping, and then welding them together. Plain, square butt joints used for butt welding thin sheet metal are shown in *Figure 6-36*. Butt joints for thicker metals, with several types of edge preparation, are shown in *Figure 6-37*. These edges can be prepared by flame cutting, shearing, flame grooving, machining, or grinding.

Plate thicknesses of 3/8 to 1/2 inch can be welded by using the single-V or single-U joints, as shown in Views A and C of *Figure 6-37*. The edges of heavier sections should be prepared as shown in Views B and D of *Figure 6-37*. The single-U groove is more satisfactory and requires less filler metal than the single-V groove when welding heavy sections and when welding in deep sections. The double-V groove joint requires approximately one-half the amount of filler metal used to produce the single-V groove joint for the same plate thickness. In general, butt joints prepared from both sides permit easier welding, produce less distortion, and ensure better weld qualities in heavy sections than joints prepared from one side only.

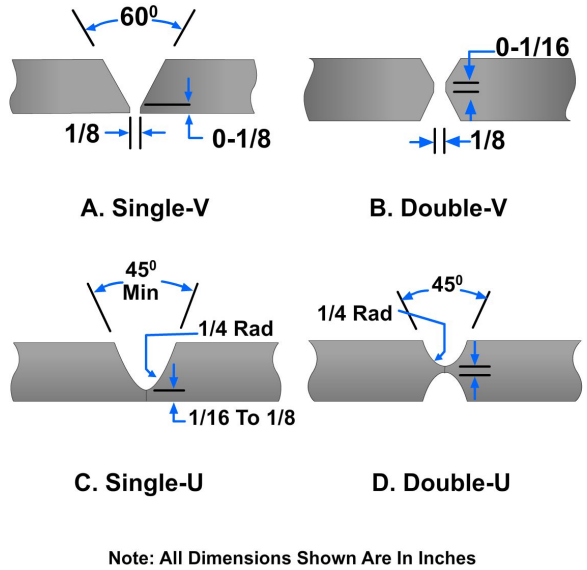


Figure 6-37 — Butt joints in heavy sections.

TEE JOINTS — Tee joints are used to weld two plates or sections whose surfaces are located approximately 90° to each other at the joint. A plain tee joint welded from both sides is shown in *Figure 6-38*. The included angle of bevel in the preparation of tee joints is approximately half that required for butt joints.

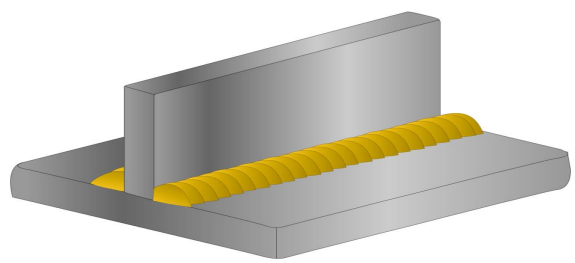


Figure 6-38 — Tee joint—single pass fillet weld.

Other edge preparations used in tee joints are shown in *Figure 6-39*. A plain tee joint, which requires no preparation other than cleaning the end of the vertical plate, and the surface of the horizontal plate, is shown in View A of *Figure 6-39*. The single-beveled joint (View B of *Figure 6-39*) is used in plates and sections up to 1/2 inch thick. The double-bevel joint (View C of *Figure 6-39*) is used on heavy plates that can be welded from both sides. The single-J joint (View D of *Figure 6-39*) is used for welding plates that are 1 inch thick or heavier where welding is done from one side. The double-J joint (View E of *Figure 6-39*) is used for welding very heavy plates from both sides.

Care must be taken to ensure penetration into the root of the weld. This penetration is promoted by root openings between the ends of the vertical members and the horizontal surfaces.

LAP JOINTS — Lap joints are used to join two overlapping members. A single lap joint, where welding must be done from one side, is shown in *View A* of *Figure 6-40*. The double lap joint is welded on both sides and develops the full strength of the welded members (*View B* of *Figure 6-40*). An offset lap joint (*View C* of *Figure 6-40*) is used where two overlapping plates must be joined and welded in the same plane. This type of joint is stronger than the single lap type, but is more difficult to prepare.

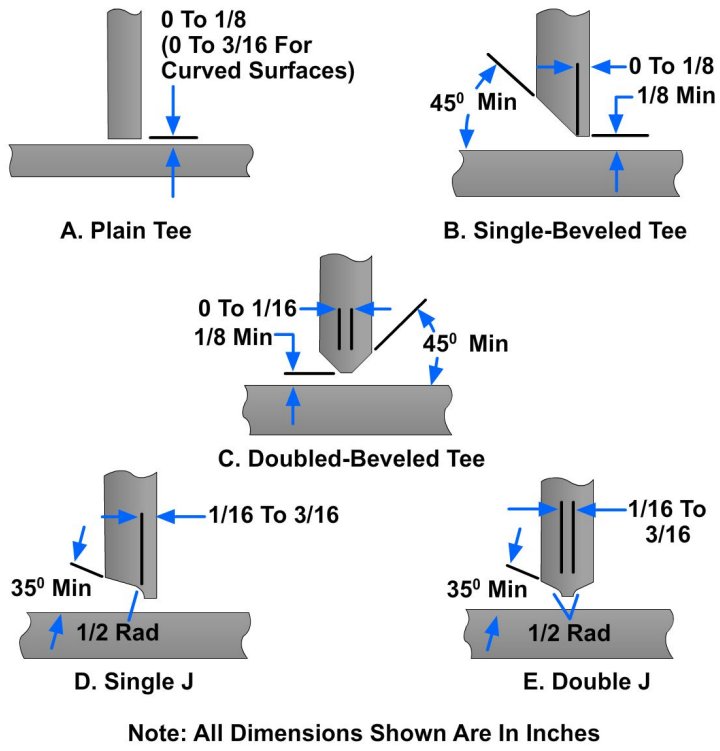


Figure 6-39 — Edge preparations for tee joint.

EDGE JOINTS —Edge joints are used to join two or more parallel or nearly parallel members. Edge joints are not very strong, and are used to join edges of sheet metal, reinforcing plates in flanges of I-beams, and for edges of angles. Two parallel plates are joined together, as shown in *View A* of *Figure 6-41*. On heavy plates, sufficient filler metal is added to fuse or melt each plate edge completely and to reinforce the joint.

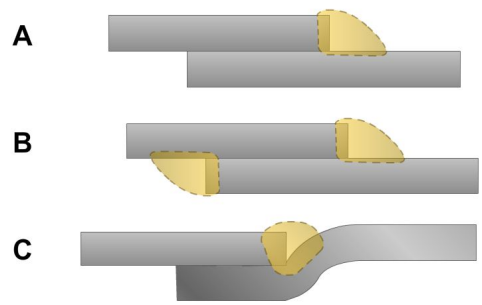


Figure 6-40 — Lap joints.

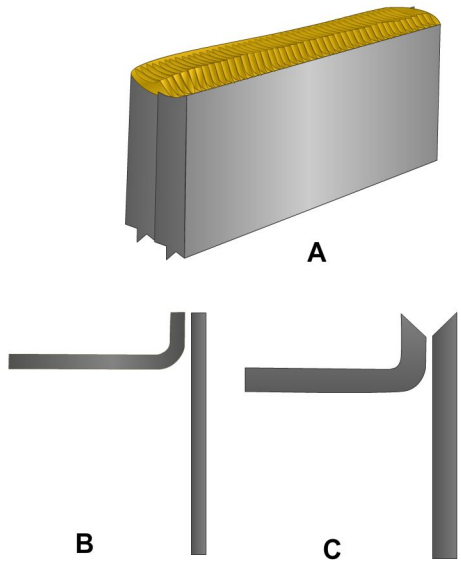


Figure 6-41 — Edge joints for light sheets and plates.

Light sheets are welded as shown in *View B* of *Figure 6-41*. No preparation is necessary other than to clean the edges and tack-weld them in position. The edges are fused together so no filler metal is required. The heavy plate joint, as shown in *View C* of *Figure 6-41*, requires that the edges be beveled to secure good penetration and fusion of the sidewalls. Filler metal is used in this joint.

CORNER JOINTS —Corner joints are used to join two members located approximately at right angles to each other in the form of an L. The fillet weld corner joint (*View A* of *Figure 6-42*) is used in the construction of boxes, box frames, and similar fabrications.

The closed corner joint (*View B* of *Figure 6-42*) is used on lighter sheets when high strength is not required at the joint. In making the joint by oxyacetylene welding, the overlapping edge is melted down and little or no filler metal is added. When the closed joint is used for heavy sections, the lapped plate is V-beveled or U-grooved to permit penetration to the root of the joint.

The open corner joint (*View C* of *Figure 6-42*) is used on heavier sheets and plates. The two edges are melted down, and filler metal is added to fill up the corner.

Corner joints on heavy plates are welded from both sides, as shown in *View D* of *Figure 6-42*. The joint is first welded from the outside, and then reinforced from the backside with a seal bead.

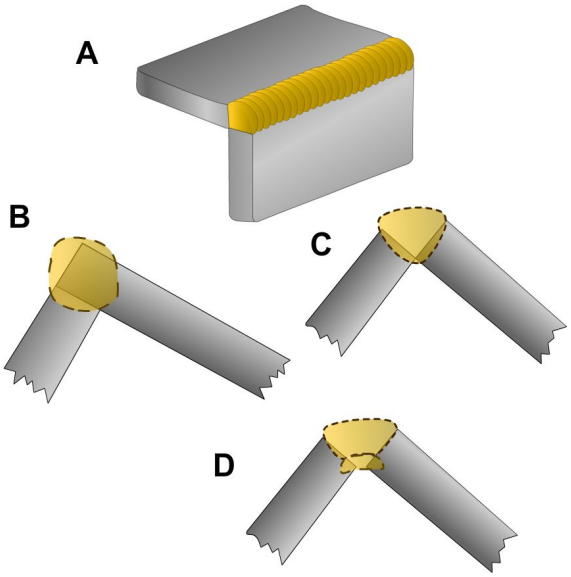


Figure 6-42 — Corner joints for sheets and plates.

Acetylene Safety Precautions

Acetylene safety precautions should be rigidly observed and enforced. Some of the more important precautions to remember are as follows:

1. Store acetylene cylinders in an upright position. They must be securely fastened to prevent shifting or falling. Do not place cylinders on sides, drop, or handle roughly. If horizontal stowage is necessary, or an acetylene cylinder is inadvertently left lying in a horizontal position, it must be placed in an upright position for a minimum of 2 hours before it can be used. (Otherwise, acetone in which the acetylene is dissolved will be drawn out with the gas.) Avoid damaging the valves or fuse plugs to prevent leakage.
2. Store acetylene cylinders in a well-protected, well-ventilated, dry place, away from heating devices or combustible materials.
3. Use acetylene from cylinders only through pressure-reducing regulators. Do not use acetylene at pressures greater than 15 psi.
4. Open the acetylene valve slowly, 1/4 to 1/2 turn. This will permit an adequate flow of gas. Never open the valve more than 1 1/2 turns of the spindle.
5. Keep sparks, flames, and heat away from acetylene cylinders.
6. Turn the acetylene cylinder so that the valve outlet will point away from the oxygen cylinder.
7. Do not interchange hose, regulators, or other apparatus intended for oxygen with those intended for acetylene.
8. Use only approved hoses and fittings with acetylene equipment. Pure copper, or copper alloys containing 67 to 99 percent copper, must not be used in piping or fittings for handling acetylene (except blowpipe or torch tips).

9. Test for leaks with soapy water—not with an open flame.
10. Make no attempt to transfer acetylene from one cylinder to another, refill an acetylene cylinder, or mix any other gas or gases with acetylene.
11. Keep valves closed on empty cylinders.
12. Should an acetylene cylinder catch fire, use a wet blanket to extinguish the fire. If this fails, spray a stream of water on the cylinder to keep it cool.
13. Crack each cylinder valve for an instant to blow dirt out of the nozzles before attaching the pressure regulator. Do not stand in front of the valve when opening it.
14. Learn to identify standard Navy cylinders by color and decals.

GAS TUNGSTEN-ARC WELDING

Gas tungsten-arc (GTA) welding is an arc welding process that produces coalescence of metals by heating them with an electric arc between a nonconsumable tungsten electrode and the base metal. The weld pool, arc, electrode, and the heated section of the work pieces are protected from atmospheric contamination by a gaseous shield; otherwise, atmospheric oxygen and nitrogen will combine with the molten weld metal and result in a weak, porous weld. The shielding gas is usually an inert gas, such as helium, argon, or a mixture of gases.

The electrode used in GTA welding is generally tungsten or a tungsten alloy because other refractory metals would erode too rapidly at the high arc temperatures involved.

The GTA welds are stronger, more ductile, and more corrosion-resistant than other types of arc welds. The weld zone has 100-percent protection from the atmosphere; therefore, no flux is required. Since no flux is required, it eliminates flux or slag inclusions in the weld, and there are no sparks, fumes, or spatter. With GTA welding, the welding heat, amount of penetration, and bead shape can be very accurately controlled, and the bead surface is smooth and uniform.

Welding Machines

Any standard dc or ac welding machine can be used to supply the current for gas tungsten-arc welding. However, it is important that the generator or transformer have good current control in the low range. This is necessary to maintain a stable arc, especially when welding thin gauge materials. Specially designed machines with all of the necessary controls are available for gas tungsten-arc welding. Many of the power supply units are made to produce both ac and dc current.

The choice of an ac or dc machine depends on what weld characteristics may be required. Some metals are joined more easily with ac current, while others get better results when dc current is used.

Welding Currents

With direct current the welding circuit may be either dc straight polarity (DCSP) or dc reverse polarity (DCRP). When the machine is set for straight polarity, the flow of electrons is from the electrode to the plate, which creates considerable heat in the plate. In reverse polarity, the flow of electrons is from the plate to the electrode, thus causing a greater concentration of heat at the electrode. See *Figure 6-43*. The intense heat at the electrode tends to melt off the end of the electrode and may contaminate the weld. Hence, for any given current, DCRP requires a larger diameter electrode than DCSP. For example, a 1/16-inch diameter tungsten electrode normally can handle about 125 amperes in a straight polarity circuit. However, if reverse polarity is used with this amount of current, the tip of the electrode will melt off. Consequently, a 1/4-inch diameter electrode will be required to handle 125 amperes of welding current.

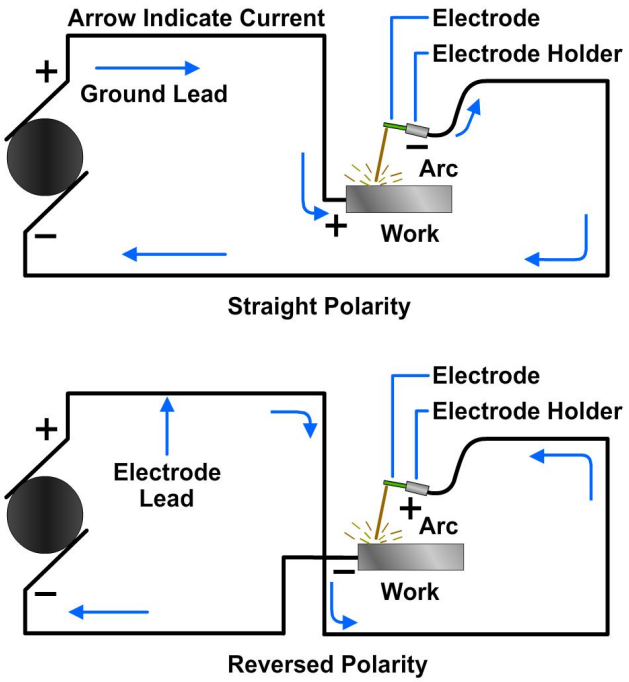


Figure 6-43 — Straight and reverse polarity in electric welding.

Polarity also affects the shape of the weld. Straight polarity produces a narrow, deep weld, whereas reverse polarity with its larger diameter electrode and lower current forms a wide and shallow weld. Therefore, DCSP is used for welding most metals because better welds are achieved. With the heat concentrated at the plate, the welding process is more rapid, and there is less distortion of the base metal.

Alternating current, high-frequency (ACHF) welding is a combination of DCSP and DCRP. One half of the complete ac cycle is DCSP and the other half is DCRP. Unfortunately, oxides, scale, and moisture on the work piece often tend to prevent the full flow of current in the reverse polarity direction. If no current whatsoever flowed in the reverse polarity direction during a welding operation, the partial or complete stoppage of current flow would cause the arc to be unstable and sometimes go out. To prevent this, ac welding machines incorporate a high-frequency current flow unit. The high-frequency current is able to jump the gap between the electrode and the work piece, piercing the oxide film and forming a path for the welding current to flow.

Welding Equipment

The GTA welding equipment is produced by many manufacturers. For this reason, it is very important to remember that the equipment being discussed in this chapter is only one of the many types that can be found throughout the Navy. However, the functions of similar component parts of different makes of machines are identical, although they may not appear to be the same.

TORCHES — Manually-operated torches are constructed to conduct both the welding current and the inert gas to the weld zone. These torches are either air- or water-cooled. Air-cooled torches are designed for welding light gauge materials where low current values are used. Water-cooled torches (*Figure 6-44*) are recommended when the welding requires amperages over 200 amps. A circulating stream of water flows around the torch to keep it from overheating. The tungsten electrode, which supplies the welding current, is held rigidly in the torch by means of a collet that screws into the body of the torch. A variety of collet sizes are available so different diameter electrodes can be used. Gas is fed to the weld zone through a nozzle, which consists of a ceramic cup. Gas cups are threaded into the torch head to provide directional and distributional control of the shielding gas. The cups are interchangeable to accommodate a variety of gas flow rates. Gas cups vary in size. The size that should be used depends upon the type and size of torch and the diameter of the electrode.

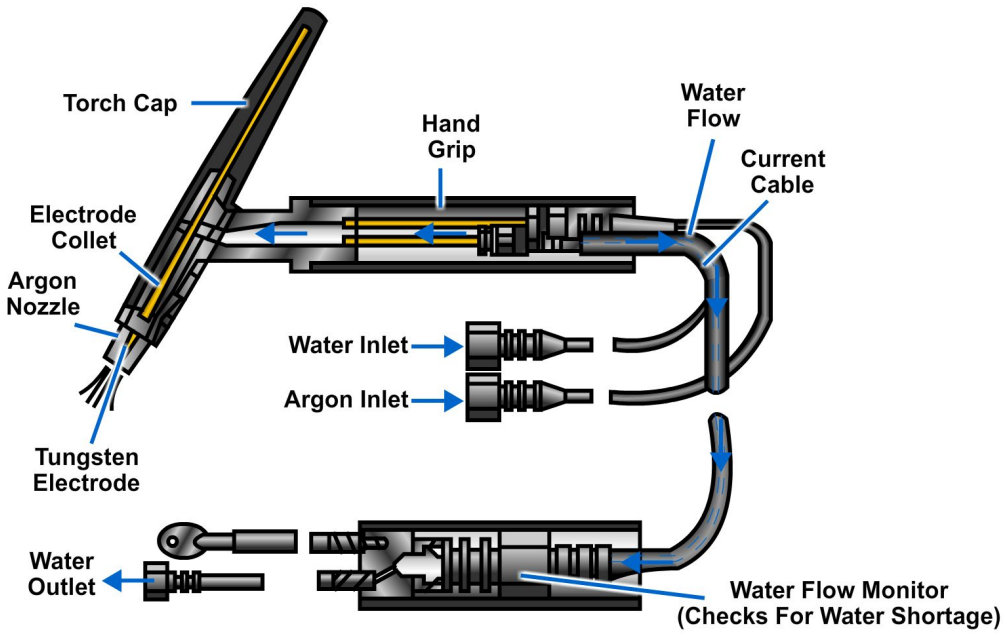


Figure 6-44 — Typical water-cooled GTA welding torch.

Pressing a control switch on the torch starts the flow of both the current and gas. On some equipment, the flow of current and gas is energized by a foot control. The advantage of the foot control is that the variable current flow can be used as the end of the weld is reached. By gradually decreasing the current, it is less likely for a cavity to remain in the end of the weld puddle and less danger of cutting short the shielding gas.

ELECTRODES — Pure tungsten, or tungsten alloyed with thorium or zirconium, is the best electrode for GTA welding. The addition of thorium increases the current capacity and electron emission, keeps the tip cooler at a given level of current, minimizes movement of the arc around the electrode tip, permits easier arc starting, and the electrode is not as easily contaminated by accidental contact with the work piece.

The diameter of the electrode selected for a welding operation is governed by the welding current to be used. Larger diameter tungsten electrodes are required with reversed polarity than with straight polarity.

To produce good welds, the tungsten electrode must be shaped correctly. The general practice is to use a pointed electrode with dc welding and a spherical end with ac

welding. It is also important that the electrode be straight, otherwise the gas flow will be off-center from the arc.

SHIELDING GASES — Shielding gas for GTA welding can be argon, helium, or a mixture of argon and helium. Argon is the most popular shielding gas used in the GTA process. Helium is rarely used because of its higher cost as compared to argon. In addition, since argon is heavier than air, it provides a better blanket over the weld. A mixture of argon and helium is sometimes used in welding metals that require a higher heat input.

Welding Procedures

Before you begin the welding process, be sure to observe the following preliminary steps:

1. Check all electrical circuit connections to make sure they are tight.
2. Check for proper electrode diameter and cup size.
3. Adjust the electrode so that it extends the appropriate distance beyond the edge of the gas cup for the particular joint being welded.
4. Check the electrode to be certain that it is firmly held in the collet. If the electrode moves in the nozzle, tighten the collet holder or gas cup. Be careful not to over tighten the gas cup because this will strip the threads.
5. Set the machine for the correct welding amperage.
6. If a water-cooled torch is to be used, turn on the water.
7. Turn on the inert gas and set it to the correct flow.

STARTING THE ARC —If using an ac machine, the electrode should not touch the metal to start the arc. To strike the arc, the welding current should be turned on first and the torch held in a horizontal position about two inches above the work. The end of the torch should be angled toward the work piece so the end of the electrode is 1/8 inch above the plate. *Figure 6-45* shows the procedure for starting the arc. The high-frequency current will jump the gap between the electrode and the plate, establishing the arc. The downward motion should be made rapidly to provide the maximum amount of gas protection to the weld zone.

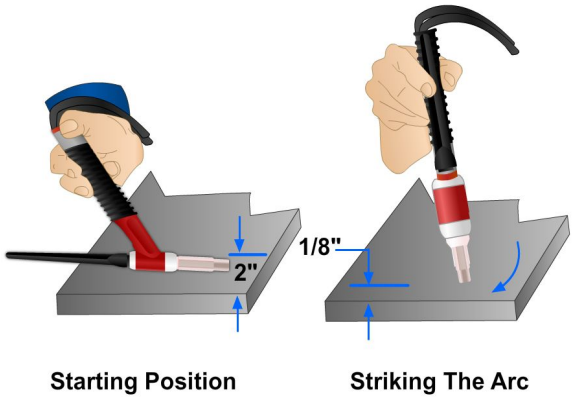


Figure 6-45 — Starting the arc.

If a dc machine is used, the torch should be held in the same position; but in this case, the electrode can touch the plate to start the arc. When the arc is struck, the electrode should be withdrawn so it is about 1/8 inch above the work piece.

STOPPING THE ARC — To stop an arc on the ac or dc machine, the electrode should be swung back to the horizontal position, as shown in *Figure 6-46*. This movement should be made rapidly to avoid marring or damaging the weld surface.

Some machines are equipped with a foot pedal to permit a gradual decrease of current. With such control, it is easier to fill the crater completely and prevent crater cracks.

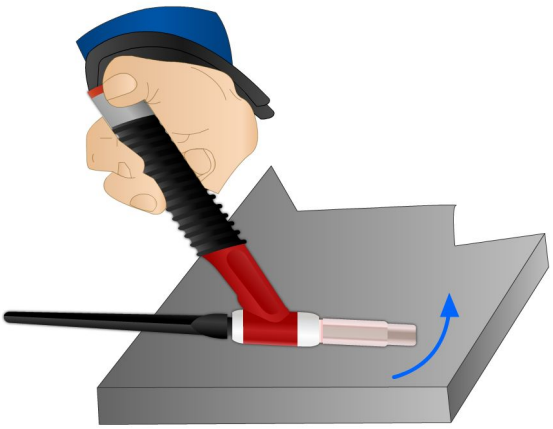


Figure 6-46 — Breaking the arc.

> ⚠ **CAUTION** ⚠
>
> If you are using a water-cooled cup, do not allow the cup to come in contact with the work when the current is on. The hot gases may cause the arc to jump the electrode to the cup instead of the plate, thereby damaging the cup. Be sure that the water flow is set according to the manufacturer's recommendations.

GAS METAL-ARC (GMA) WELDING

The process of GMA welding is one that produces fusion by heating with an electric arc between a consumable wire electrode and the work. The arc and weld puddle are shielded from the atmosphere by a gas, or a gas and a flux. The shielding gas protects the molten weld metal from oxidation or contamination by the surrounding atmosphere.

The consumable-wire electrode for GMA welding is fed through the torch to the welding arc at the same rate as the heat of the arc melts off the end of the electrode. The shielding gas flows through the torch to the arc area. The melting rate of the filler wire depends on the level of the welding current, but must be the same as the feeding rate to maintain a constant arc length. This means that a constant balance must be maintained between the welding current and wire-feeding rate.

GMA Welding Equipment

There are numerous types and models of GMA welding equipment used in the Navy. Each must have a source of DCRP welding current; a wire feed unit for feeding the wire filler metal; a welding gun for directing the wire filler and shielding gas to the weld area; and a gas supply. *Figure 6-47* shows GMA welding equipment.

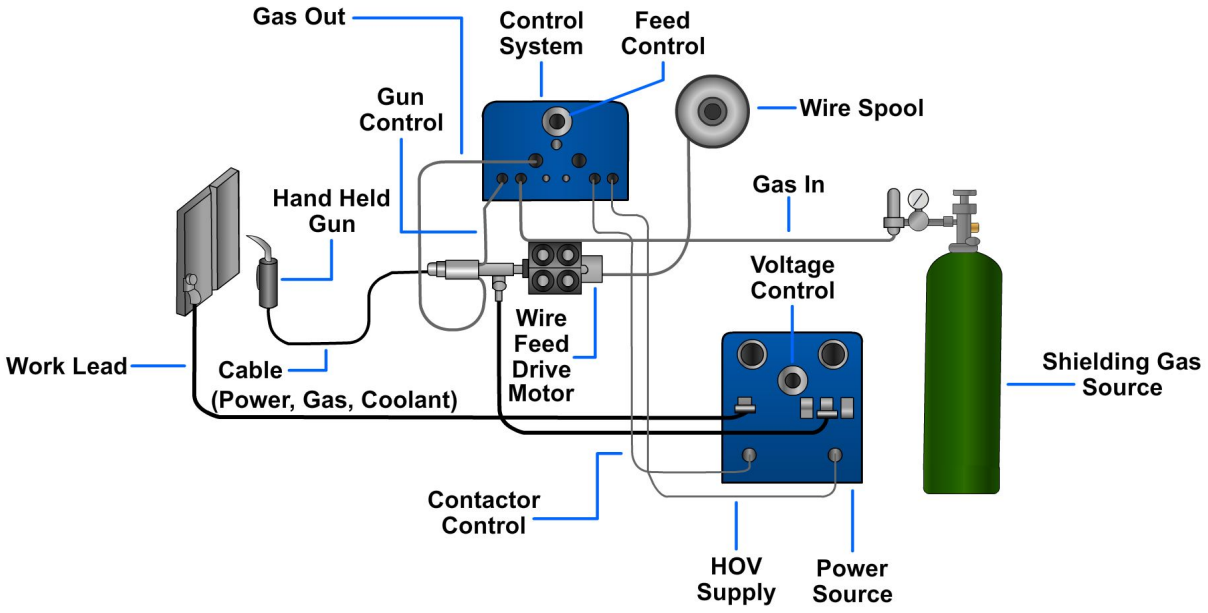


Figure 6-47 — GMA welding equipment.

POWER SUPPLY — The recommended machine for GMA welding is a rectifier or motor generator that supplies direct current with normal limits of 200 to 250 amperes. Most generally, DCRP is used because it provides maximum heat for better melting, deeper penetration, and excellent cleaning action.

Two types of direct-current power sources are used for GMA welding—the constant-current type and the constant-voltage type. The constant-current power source is used if the controls and wire-driven mechanism control the arc length by varying the wire-drive speed. In this case, a change in the arc length causes a change in the arc voltage. The control circuit senses this change and varies the wire-feed speed to bring the arc length back to the desired value.

When arc length is controlled through changes in welding current, constant-voltage power supplies are used. The wire-feed speed is constant. Any changes in arc length will cause automatic changes in welding current, which compensate for the arc-length change. If the arc length becomes shorter, the welding current automatically increases. This causes the wire to melt faster and the arc length to increase. The reverse happens if the arc is lengthened during welding.

WIRE FEEDING MECHANISM — The wire feeding mechanism automatically drives the electrode wire from the wire spool to the welding gun and arc at a uniform rate. The speed of the wire feeding mechanism is adjustable, so that the wire-feed speed can be set to equal the melting rate. If the drive unit is designed to be used with a constant-voltage power source, the speed is set before welding starts, and remains constant during welding. If the unit is to be used with a constant-current voltage power source, the drive unit speed is varied automatically by an electronic control device.

WELDING GUN — The function of the welding gun is to deliver the wire, shielding gas, and welding current to the arc area. Guns are either the push or pull type. The pull gun has drive rolls that pull the welding wire from the wire feeder, and the push gun has the wire pushed to it by drive rolls in the wire feeder itself.

Both guns have a trigger switch that controls the wire feed and arc as well as the shielding gas. When the trigger is released, the wire feed, arc, and shielding gas stop

immediately. With some equipment, a timer is included to permit the shielding gas to flow for a predetermined time to protect the weld until it solidifies.

Guns are available with a straight or curved nozzle. The curved nozzle provides easy access to intricate joints and difficult to weld patterns.

SHIELDING GAS — Shielding gases in the gas metal-arc process are used primarily to protect the molten metal from oxidation and contamination. Other factors must be considered, however, in selecting the right gas for a particular application. Shielding gas can influence arc and metal transfer characteristics, weld penetration, width of fusion zone, surface-shape patterns, welding speed, and undercut tendency. Inert gases, such as argon and helium, provide the necessary shielding because they do not form compounds with any other substance and are insoluble in molten metal. When used for welding ferrous metals, arc action may be erratic and the metal transfer globular. Therefore, it is necessary to add controlled quantities of reactive gases to achieve good arc action and metal transfer with these materials.

Helium is preferable for welding thick materials, especially those with high heat conductivity, such as copper, aluminum, and some copper-base alloys. Helium has a higher ionization potential, which results in a greater weld heat at a given amperage. Argon is more suitable for use with lighter-gauge materials and materials of lower heat conductivity because it produces lower weld heat.

GMA Welding Techniques

Before welding with GMA welding equipment, all controls should be properly adjusted, all connections should be correctly made, and all safety precautions need to be observed. Protective clothing, including a helmet with a suitable filter lens, should be worn. The welding torch should be held at an angle of between 5° and 20° to the work, as shown in *View B* of *Figure 6-48*. The weight of the welding cable and gas hose should be supported across the welder's shoulder to ensure free movement of the welding torch. The torch should be held close to, but not touching, the work piece. The welder's helmed should then be lowered and the trigger squeezed to start the flow of shielding gas and energize the welding circuit. The wire-feed motor is not energized until the wire electrode comes in contact with the work piece. The torch should be moved toward the work, touching the wire electrode to the work with a sideways scratching motion, as shown in *View A* of *Figure 6-48*. To prevent sticking, it is necessary to pull the gun back quickly, about 1/2 inch, the instant contact is made between the wire electrode and the work piece. The arc will strike as soon as contact is made, and the wire-feed motor will feed the wire automatically as long as the trigger is held.

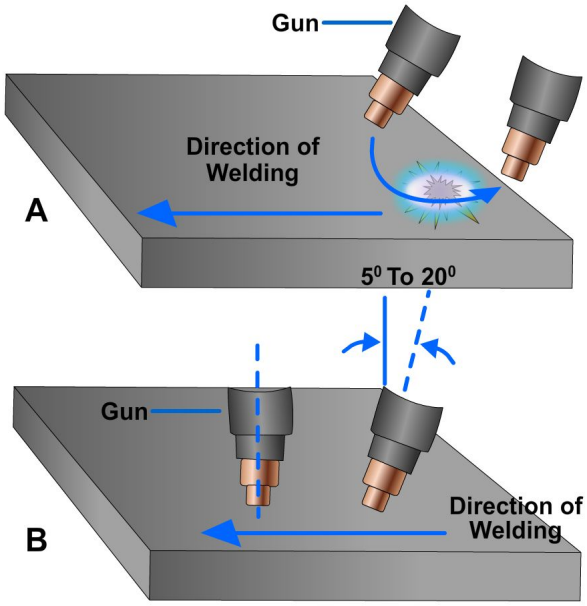


Figure 6-48 — Gas metal-arc welding. (A) striking the arc; (B) gun angle.

To break the arc, the welder just needs to release the trigger. This breaks the welding circuit and also de-energizes the wire-feed motor. If the wire electrode sticks to the work

when it strikes the arc, or at any time during welding, the trigger should be released and the wire should be clipped with a pair of pliers or side cutters.

A properly established arc has a soft, sizzling sound. The arc itself is about 1/4 inch long, or about one-half the distance between the gun nozzle and the work. When the arc does not sound right, the wire-feed control dial or the welding machine itself may need to be adjusted. For example, a loud, crackling sound indicates that the arc is too short and the wire-feed speed is too fast. This can be corrected by moving the wire-feed speed dial slightly counterclockwise. This decreases wire-feed speed and increases arc length. A clockwise movement of the dial has the opposite effect. With experience, a welder will soon be able to recognize the sound of the proper length of arc to use.

The proper position of the welding torch and material is important. The flat position of the material is preferred for most joints because this position improves the molten metal flow, bead contour, and gives better gas protection.

The alignment of the welding wire in relation to the joint is very important. The welding wire should be on the center line of the joint if the pieces to be joined are of equal thickness. If the pieces are unequal in thickness, the wire may be moved toward the thicker piece.

Correct work and travel angles are necessary for correct bead formations. The travel angle may be a push angle or a drag angle, depending upon the position of the gun. If the gun is angled back toward the beginning of the weld, the travel angle is called a "drag" angle. If the gun is pointed ahead toward the end of the weld, the travel angle is called a "push" angle.

When the gun is ahead of the weld, it is referred to as pulling the weld metal. If the gun is behind the weld, it is referred to as pushing the metal. The pulling technique is usually best for light gauge metals and the pushing technique for heavy materials.

Generally, the penetration of beads deposited with the pulling technique is greater than with the pushing technique. Furthermore, since the welder can see the weld crater easier in a pulling action, he/she can produce high quality welds more consistently. On the other hand, pushing permits the use of higher welding speeds and produces less penetrating and wider welds.

WELDING SAFETY PRECAUTIONS

Accidents frequently occur in welding operations, and in many instances, they result in serious injury to the welder or other personnel working in the immediate area. Many welders fail to realize that accidents often occur NOT because of a lack of protective equipment, but because of carelessness, lack of knowledge, and the misuse of available equipment.

The welder should have a thorough *knowledge* of safety precautions relating to the job. But that is not all. The welder should also consider it a responsibility to carefully *observe* the applicable safety precautions. In welding, being careless can cause serious injury not only to the welder, but to others as well.

Bear in mind that safety precautions for the operation of welding equipment vary considerably because of the different types of equipment involved. Therefore, only general precautions on operating metal arc-welding equipment are given here. For specific instructions on the operation, maintenance, and care of individual equipment, the equipment manufacturer's instruction manual should be used as a guide.

In regard to general precautions, a welder should know the equipment and how to operate it. Using only approved welding equipment; it should be kept in good, clean condition. Before starting to work, the welding machine frame should be grounded, neither terminal of the welding generator should be bonded to the frame, and all electrical connections should be checked to ensure they are securely made. The ground connection must be attached firmly to the work, not merely laid loosely upon it.

Welding cables should be dry and free of oil or grease. Cables should be kept in good condition, and, at all times, appropriate steps taken to protect them from damage. If it is necessary to carry cables some distance from the machines, the cables should be run overhead, if possible, and adequate supporting devices used.

When using a portable machine, care should be used to see that the primary supply cable is laid separately so that it does not become entangled with the welding supply cable. Any portable equipment mounted on wheels should be securely blocked to prevent accidental movement during the welding operations.

When a welder stops work for any appreciable length of time, the equipment *must* be de-energized. When not in use, the equipment should be completely disconnected from the source of power.

The work area should be kept neat and clean. Among other things, adopting the practice of disposing of hot electrode stubs in a metal container.

Proper eye protection is of the utmost importance, not only to the welding operator, but for other personnel in the vicinity of the welding operation. Eye protection is necessary because of the hazards posed by stray flashes, reflected glare, flying sparks, and globules of molten metal.

HEAT TREATMENT OF METALS

This section covers the forms and principles of heat treatment in general. Ferrous and nonferrous heat treatment of metals is covered. Covered information is for training purposes only. When actually performing heat treatment tasks, you must refer to the applicable technical publications.

Heat treatment is a series of operations involving the heating and cooling of a metal or alloy in the solid state for the purpose of obtaining certain desirable characteristics. The rate of heating and cooling determines the crystalline structure of the material. In general, both ferrous metals (metals with iron bases) and nonferrous metals, as well as their alloys, respond to some form of heat treatment. Almost all metals have a critical temperature at which the grain structure changes. Successful heat treatment, therefore, depends largely on knowledge of these temperatures as well as the time required to produce the desired change.

PRINCIPLES OF HEAT TREATMENT

The results that may be obtained by heat treatment depend, to a great extent, on the structure of the metal and the manner in which the structure changes when the metal is heated and cooled. A pure metal cannot be hardened by heat treatment because there is little change in its structure when heated. On the other hand, most alloys respond to heat treatment because their structures change with heating and cooling.

An alloy may be in the form of a solid solution, mechanical mixture, or a combination of a solid solution and a mechanical mixture. When an alloy is in the form of a solid solution, the elements and compounds that form the alloy are absorbed, one into the

other, in much the same way that salt is dissolved in a glass of water. The constituents cannot be identified even under a microscope.

When two or more elements or compounds are mixed, but can be identified by microscopic examination, a mechanical mixture is formed. A mechanical mixture might be compared to the mixture of sand and gravel in concrete. The sand and gravel are both visible. Just as the sand and gravel are held together and kept in place by the mixture of cement, the other constituents of an alloy are embedded in the mixture formed by the base metal.

An alloy that is in the form of a mechanical mixture at ordinary temperatures may change to a solid solution when heated. When cooled back to normal temperature, the alloy may return to its original structure. On the other hand, it may remain a solid solution or form a combination of a solid solution and mechanical mixture. An alloy that consists of a combination of a solid solution and mechanical mixture at normal temperatures may change to a solid solution when heated. When cooled, the alloy may remain a solid solution, return to its original structure, or form a complex solution.

Heat treatment involves a cycle of events. These events are heating, generally done slowly to ensure uniformity; soaking, or holding the metal at a given temperature for a specified length of time; and cooling, or returning the metal to room temperature, sometimes rapidly, sometimes slowly.

Heating

Uniform temperature is of primary importance in the heating cycle. If one section of a part is heated more rapidly than another, the resulting uneven expansion often causes distortion or cracking of the part. Uniform heating is obtained by slow heating.

The rate at which a part may be heated depends on several factors. One important factor is the heat conductivity of the metal. A metal that conducts heat readily may be heated at a faster rate than one in which heat is not absorbed as rapidly throughout the part. The condition of the metal also affects the rate at which it may be heated. For example, the heating rate for hardened tools and parts should be slower than for metals that are not in a stressed condition. Finally, size and cross section have an important influence on the rate of heating. Parts large in cross section require a slower heating rate than thin sections. This slower heating rate is necessary so that the interior will be heated to the same temperature as the surface. It is difficult to uniformly heat parts that are uneven in cross section, even though the heating rate is slow. However, such parts are less apt to be cracked or excessively warped when the heating rate is slow.

Soaking

The object of heat-treating is to bring about changes in the properties of metal. To accomplish this, the metal must be heated to the temperature at which structural changes take place within the metal. These changes occur when the constituents of the metal go into the solution. Once the metal is heated to the proper temperature, it must be held at that temperature until the metal is heated throughout and the changes have time to take place. This holding of the metal at the proper temperature is called *soaking*. The length of time at that temperature is called the *soaking period*. The soaking period depends on the chemical analysis of the metal and the mass of the part. When steel parts are uneven in cross section, the soaking period is determined by the heaviest section. In heating steels, the metal is seldom raised from room temperature to the final temperature in one operation. Instead, the steel is slowly heated to a temperature below the point at which the solid solution begins, and it is then held at that temperature until

heat is absorbed throughout the metal. This process is called preheating. Following the preheating, the steel is quickly heated to the final temperature. Preheating aids in obtaining uniform temperature throughout the part being heated, and, in this way, reduces distortion and cracking. When a part is of intricate design, it may have to be preheated at more than one temperature to prevent cracking and excessive warping. As an example, assume that an intricate part is to be heated to 1500°F (815°C) for hardening. This part might be slowly heated to 600°F (315°C), be soaked at this temperature, then be heated slowly to 1200°F (649°C), and then soaked at that temperature. Following the second preheat; the part would be heated quickly to the hardening temperature. Nonferrous metals are seldom preheated because they usually do not require it. Furthermore, preheating tends to increase the grain size in these metals.

Cooling

After being heated to the proper temperature, the metal must be returned to room temperature to complete the heat-treating process. The metal is cooled by placing it in direct contact with a gas, liquid, or solid, or some combination of these. The solid, liquid, or gas used to cool the metal is called a "cooling medium." The rate at which the metal should be cooled depends on both the metal and the properties desired. The rate of cooling also depends on the medium; therefore, the choice of a cooling medium has an important influence on the properties obtained.

Cooling metals rapidly is called "quenching," and the oil, water, brine, or other mediums used for rapid cooling is called a "quenching medium." Since most metals must be cooled rapidly during the hardening process, quenching is generally associated with hardening. However, quenching does not always result in an increase in hardness. For example, copper is usually quenched in water during annealing. Other metals, air-hardened steels for example, may be cooled at a relatively slow rate for hardening.

Some metals are easily cracked or warped during quenching. Other metals may be cooled at a rapid rate with no ill effects. Therefore, the quenching medium must be chosen to fit the metal. Brine and water cool metals quickly, and should be used only for metals that require a rapid rate of cooling. Oil cools at a slower rate and is more suitable for metals that are easily damaged by rapid cooling. Generally, carbon steels are considered water-hardened and alloy steels oil-hardened. Nonferrous metals are usually quenched in water.

FORMS OF HEAT TREATMENT

The various heat-treating processes are similar in that they involve the heating and cooling of metals. They differ, however, in the temperatures to which the metals are heated, the rates at which they are cooled, and, of course, in the final result. The most common forms of heat treatment for ferrous metals are annealing, normalizing, hardening, tempering, and case hardening. Most nonferrous metals can be annealed but never tempered, normalized, or case-hardened. Successful heat-treating requires close control over all factors affecting the heating and cooling of metals. Such control is possible only when the proper equipment is available, and the equipment is selected to fit the particular job.

Annealing

Annealing is used to reduce residual stresses, induce softness, alter ductility, or refine the grain structure. Maximum softness in metal is accomplished by heating it to a point

above the critical temperature, holding it at that temperature until the grain structure has been refined, and then followed by slow cooling.

Normalizing

Normalizing is a process whereby iron base alloys are heated to approximately 100°F (56°C) above the upper critical temperature, followed by cooling to room temperature in still air. Normalizing is used to establish materials of the same nature with respect to grain size, composition, structure, and stress.

Hardening

Hardening is accomplished by heating the metal slightly in excess of the critical temperature, and then rapidly cooling by quenching in oil, water, or brine. This treatment produces a fine grain structure, extreme hardness, maximum tensile strength, and minimum ductility. Generally, material in this condition is too brittle for most practical uses, although this treatment is the first step in the production of high-strength steel.

Tempering

Tempering (drawing) is a process generally applied to steel to relieve the strains induced during the hardening process. It consists of heating the hardened steel to a temperature below the critical range, holding this temperature for a sufficient period, and then cooling in water, oil, or air. In this process, the degrees of strength hardness and ductility obtained depend directly upon the temperature to which the steel is heated. High-tempering temperatures improve ductility at the sacrifice of tensile, yield strength, and hardness.

Case Hardening

The objective in case hardening is to produce a hard case over a tough core. Case hardening is ideal for parts that require a wear-resistant surface and, at the same time, must be tough enough internally to withstand the applied loads. The steels best suited to case hardening are the low-carbon and low-alloy steels. If high-carbon steel is case-hardened, the hardness penetrates the core and causes brittleness. In case hardening, the surface of the metal is changed chemically by inducing a high carbide or nitride content. The core is unaffected chemically. When heat-treated, the surface responds to hardening while the core toughens. The common methods of case hardening are carburizing, nitriding, and cyaniding.

CARBURIZING — Carburizing consists of holding the metal at an elevated temperature while it is in contact with a solid or gaseous material rich in carbon. The process requires several hours, as time must be allowed for the surface metal to absorb enough carbon to become high-carbon steel. The material is then quenched and tempered to the desired hardness.

NITRIDING — Nitriding consists of holding special alloy steel, at temperatures below the critical point, in anhydrous ammonia. Absorption of nitrogen as iron nitride into the surface of the steel produces a greater hardness than carburizing, but the hardened area extends to a lesser depth.

CYANIDING — Cyaniding is a rapid method of producing surface hardness on an iron base alloy of low-carbon content. It may be accomplished by immersion of the steel in a molten bath of cyanide salt, or by applying powdered cyanide to the surface of the heated steel. The temperature of the steel during this process should range from

1400°F (760°C) to 1650°F (899°C), depending upon the type of steel, depth of case desired, type of cyanide compound, and time exposed to the cyanide. The material is dumped directly from the cyanide pot into the quenching bath.

HEAT TREATMENT OF FERROUS METALS (STEEL)

The first important consideration in the heat treatment of a steel part is to know its chemical composition. This, in turn, determines its upper critical point. When the upper critical point is known, the next consideration is the rate of heating and cooling to be used. Uniform-heating furnaces, proper temperature controls, and suitable quenching mediums are used in carrying out these operations.

Principles of Heat Treatment of Steel

Changing the internal structure of a ferrous metal is accomplished by heating it to a temperature above its upper critical point, holding it at that temperature for a time sufficient to permit certain internal changes to occur, and then cooling to atmospheric temperature under predetermined, controlled conditions.

At ordinary temperatures, the carbon in steel exists in the form of particles of iron carbide scattered throughout the iron mixture known as *ferrite*. The number, size, and distribution of these particles determine the hardness of the steel. At elevated temperatures, the carbon is dissolved in the mixture in the form of a solid solution called "austenite," and the carbide particles appear only after the steel has been cooled. If the cooling is slow, the carbide particles are relatively coarse and few. In this condition the steel is soft. If cooling is rapid, as by quenching in oil or water, the carbon precipitates as a cloud of very fine carbide particles, and the steel is hardened. The fact that the carbide particles can be dissolved in austenite is the basis of the heat treatment of steel. The temperatures at which this transformation takes place are called the "critical points," and vary with the composition of the steel. The element normally having the greatest influence is carbon. The various heat-treating procedures for commonly used aircraft steels are outlined in *Aerospace Metals—General Data and Usage Factors*, NAVAIR 01-1A-9.

Forms of Heat Treatment of Steel

There are different forms of heating ferrous materials such as steel. The methods covered in this chapter are hardening, quenching, tempering, annealing, normalizing, and case hardening. Terms such as *carburizing, cyaniding, and nitriding* are also discussed.

HARDENING —Heat treatment considerably transforms the grain structure of steel, and it is while passing through a critical temperature range that steel acquires hardening power. When a piece of steel is heated slowly and uniformly beyond a red heat, its appearance will increase in brightness until a certain temperature is reached. The color will change slightly, becoming somewhat darker, which may be taken as an indication that a transformation is taking place within the metal (pearlite being converted into austenite). When this change of state is complete, the steel will continue to increase in brightness, and if cooled quickly to prevent the change from reversing, hardness will be produced. If, instead of being rapidly quenched, the steel is allowed to cool slowly, the metal will again pass through a change of state, and the cooling rate will be momentarily arrested.

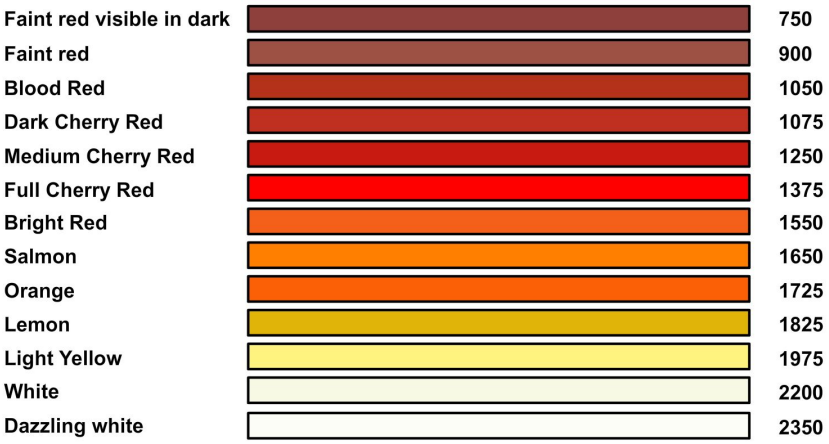
To obtain a condition of maximum hardness, it is necessary to raise the temperature of the steel sufficiently high to cause the change of state to fully complete itself. This temperature is known as the *upper critical point*. Steel that has been heated to its upper critical point will harden completely if rapidly quenched; however, in practice, it is necessary to exceed this temperature by approximately 50°F (28°C) to 100°F (56°C) to ensure thorough heating of the inside of the piece. If the upper critical temperature is exceeded too much, an unsatisfactory coarse grain size will be developed in the hardened steel.

Successful hardening of steel will largely depend upon the following factors:

1. Control over the rate of heating, specifically to prevent cracking of thick and irregular sections
2. Thorough and uniform heating through sections to correct hardening temperatures
3. Control of furnace atmosphere, in the case of certain steel parts, to prevent scaling and decarburization
4. Correct heat capacity, viscosity, and temperature of quenching media, to harden adequately and to avoid cracks

When heating steel, accurate instruments should be used to determine the temperature. At times, however, such instruments are not available, and in such cases, the temperature of the steel may be judged approximately by its color. The temperatures corresponding to various colors are given in *Table 6-1*; however, the accuracy with which temperatures may be judged by colors depends on the experience of the worker and on the light in which the work is being done.

Table 6-1 — Color Chart for Steel at Various Temperatures



Color — Perceived colors depend on lighting.	Temperature F°	Temperature C°
Faint red visible in dark	750	399
Faint red	900	482
Blood Red	1050	565
Dark Cherry Red	1075	579
Medium Cherry Red	1250	677
Full Cherry Red	1375	746
Bright Red	1550	843
Salmon	1650	899
Orange	1725	940
Lemon	1825	996
Light Yellow	1975	1079
White	2200	1204
Dazzling white	2350	1288

QUENCHING PROCEDURE —A number of liquids may be used for quenching steel. Both the media and the form of the bath depend largely on the nature of the work to be cooled. It is important that a sufficient quantity of the media be provided to allow the metal to be quenched without causing an appreciable change in the temperature of the bath. This is particularly important where many articles are to be quenched in succession.

The tendency of steel to warp and crack during the quenching process is difficult to overcome because certain parts of the article cool more rapidly than others. Whenever the transformation of temperature is not uniform, internal strains are set up in the metal that results in warping or cracking, depending on the severity of the strains. Irregularly shaped parts are particularly susceptible to these conditions, although parts of an even section are often affected in a similar manner. Operations such as forging and machining may set up internal strains in steel parts; therefore, it is advisable to normalize articles before attempting the hardening process. The following recommendations will greatly reduce the warping tendency and should be carefully observed:

1. An article should never be thrown into the bath. By permitting it to lie on the bottom of the bath, it is apt to cool faster on the top side than on the bottom side, thus causing it to warp or crack.
2. The article should be slightly agitated in the bath to destroy the coating of vapor, which might prevent it from cooling rapidly.
3. An article should be quenched in such a manner that all parts will be cooled uniformly and with the least possible distortion.
4. Irregularly shaped sections should be immersed in such a manner that the area with the biggest section enters the bath first.

Quenching Media — In certain cases water is used in the quenching of steel during the hardening process. The water bath temperature is normally held at 65°F (18°C). For specific applications, other bath temperatures may be used; however, cold water may warp or crack the part, and hot water may not produce the required hardness.

A 10-percent salt brine solution is used when higher cooling rates are desired. A 10-percent salt brine solution is made by dissolving .89 pounds of salt per gallon of water.

Oil is much slower in action than water, and the tendency of heated steel to warp or crack when quenched may be greatly reduced by its use. Unfortunately, parts made from high-carbon steel will not develop maximum hardness when quenched in oil unless they are quite thin in cross section. In aircraft parts, however, it is generally used, and is recommended in all cases where it will produce the desired degree of hardness.

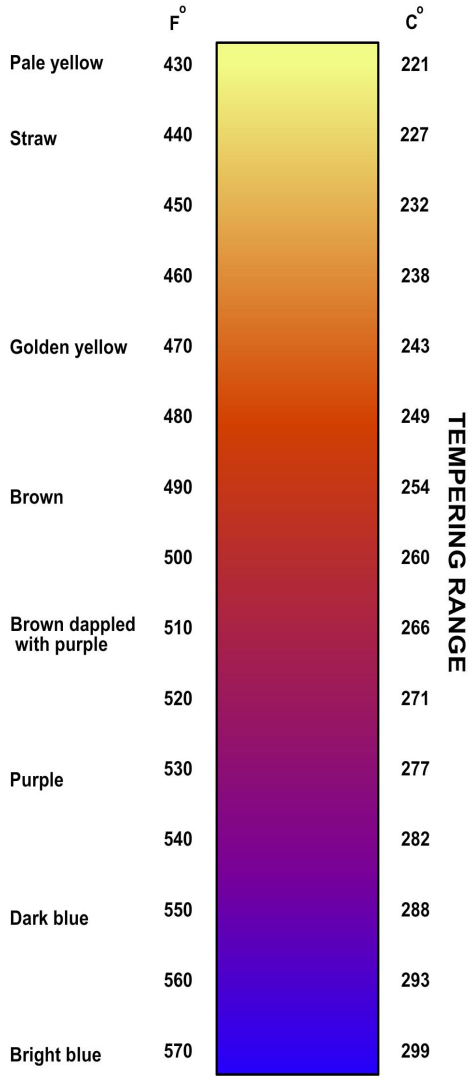
For many articles, a bath of water covered by a film of oil is occasionally used. When the steel is plunged through this oil film, a thin coating will adhere to it. This action retards the cooling of the water slightly, thus reducing the tendency to crack due to contraction.

Straightening of Parts Warped in Quenching — Warped parts must be straightened by first heating to below the tempering temperature of the article, and then applying pressure. This pressure should be continued until the piece is cooled. It is desirable to retemper the part after straightening at the straightening temperature. No attempt should be made to straighten hardened steel without heating, regardless of the number of times it has been previously heated. Steel in its hardened condition cannot be bent or sprung cold with any degree of safety.

TEMPERING — Steel that has been hardened by rapid cooling from a point slightly above its critical range is often harder than necessary, and generally too brittle for most purposes. In addition, it is under severe internal strain. To relieve the strains and reduce brittleness, the metal is usually **tempered**. This is accomplished in the same types of furnaces that are used for hardening and annealing.

As in the case of hardening, tempering temperatures may be approximately determined by color. These colors appear only on the surface and are due to a thin film of oxide, which forms on the metal after the temperature reaches 428°F (220°C). To see the tempering colors, you must brighten the surface. When tempering by the color method, an open flame or heated iron plate is ordinarily used as the heating medium. Although the color method is convenient, it should not be used unless adequate facilities for determining temperatures are not obtainable. The temperatures and corresponding oxide colors are given in *Table 6-2*.

Table 6-2 — Color Chart for Various Tempering Temperatures of Carbon Steel



ANNEALING AND NORMALIZING — When steel is heated to a point above its critical range, a condition referred to as "austenite" is produced. If slowly cooled from above its critical temperature, the austenite is broken down and a succession of other conditions is produced, each being normal for a particular range of temperatures. Starting with austenite, these successive conditions are *martensite, troostite, sorbite,* and finally *pearlite*.

The most important step in annealing is to raise the temperature of the metal to the critical point, as any hardness that may have existed will then be completely removed. Strains that may have been set up through heat treatment will be eliminated when the steel is heated to the critical point, and then restored to its lowest hardness by slow cooling. In annealing, the steel must never be heated more than approximately 50° TO 75°f (29° TO 40°C) above the critical point. When large articles are annealed, sufficient time must be allowed for the heat to penetrate the metal.

Steel is usually subjected to the annealing process for the following purposes:

1. To increase its ductility by reducing hardness and brittleness
2. To refine the crystalline structure and remove residual stresses as steel that has been cold worked is usually annealed to increase its ductility

Assuming that the part to be annealed is heated to the proper temperature, the required slow cooling may be accomplished in several ways, depending on the metal and the degree of softness required.

Normalizing, although involving a slightly different heat treatment, may be classed as a form of annealing. This process removes all strains due to machining, forging, bending, and welding. Normalizing can only be accomplished with a good furnace, where the temperatures and the atmosphere may be closely regulated and held constant throughout the entire operation. A reducing atmosphere will normalize the metal with a minimum amount of oxide scale, while an oxidizing atmosphere will leave the metal heavily coated with scale, thus preventing proper development of hardness in any subsequent hardening operation. The articles are put in the furnace and heated to a point above the critical temperature of the steel. After the parts have been held at this temperature for a sufficient time to allow the heat to penetrate to the center of the section, they must be removed from the furnace and cooled in still air. Drafts will result in uneven cooling, which will again set up strains in the metal.

Prolonged soaking of the metal at high temperatures must be avoided, as this practice will cause the grain structure to enlarge. The length of time required for the soaking temperature will depend upon the mass of metal being treated.

CASE HARDENING — In many instances, it is desirable to produce a hard, wear-resistant surface or "case" over a strong, tough core. Treatment of this kind is known as "case hardening." This treatment may be accomplished in several ways; the principal ways being carburizing, cyaniding, and nitriding.

Carburizing — When steel is heated, the pores of the metal expand, allowing it to absorb any gases to which it is exposed. By heating steel while it is in contact with a carbonaceous substance, carbonic gases given off by this material will penetrate the steel to an amount proportional to the time and temperature.

The carburizing process may be applied to plain carbon steels provided they are within the low-carbon range. Specifically, the carburizing steels are those that contain no more than 0.20 percent carbon. The lower the carbon content in the steel, the more readily it will absorb carbon during the carburizing process.

The amount of carbon absorbed and the thickness of the case obtained increase with time; however, the carburization progresses more slowly as the carbon content increases during the process. The length of time required to produce the desired degree of carburization and depth of the case depend upon the composition of the metal, the kind of carburization material used, and the temperature to which the metal is subjected. It is apparent that in carburizing, carbon travels slowly from the outside toward the center; therefore, the proportion of carbon absorbed must decrease from the outside to the center.

A common method of carburizing is called "pack carburizing." When carburizing is to be done by this method, the steel parts are packed with the carburizing material in a sealed steel container to prevent the solid carburizing compound from burning and retaining the carbon monoxide and dioxide gases. The container should be placed in a position to allow the heat to circulate entirely around it. The furnace must be brought to the carburizing temperature as quickly as possible, and held at this heat from 1 to 16 hours, depending upon the depth of the case desired and the size of the work. After carburizing, the container should be removed and allowed to cool in the air, or the parts removed from the carburizing compound and quenched in oil or water. The air-cooling, although slow, reduces warpage, and is advisable in many cases.

In another method of carburizing, called "gaseous carburizing," a carbonaceous material is introduced into the furnace atmosphere. When the steel parts are heated in this carburizing atmosphere, carbon monoxide combines with the iron to produce results that are practically the same as those described under the pack carburizing process.

Cyaniding — Steel parts may be surface-hardened by heating while in contact with a cyanide salt, followed by quenching. Only a thin case is obtained by this method; therefore, it is seldom used in connection with aircraft construction or repair. However, cyaniding is a rapid and economical method of case hardening, and may be used in some instances for relatively unimportant parts. The work to be hardened is immersed in a bath of molten sodium or potassium cyanide from 30 to 60 minutes. The cyanide bath should be maintained at a temperature of 1400° to 1650°F (760° to 899°C). Immediately after removal from the bath, the parts are quenched in water. The case obtained in this manner is due principally to the formation of carbides on the surface of the steel. The use of a closed pot is required for cyaniding, as cyanide vapors are extremely poisonous.

Nitriding — This method of case hardening is advantageous because a harder case is obtained than by carburizing. Nitriding can only be applied to certain special steel alloys, one of the essential constituents of which is aluminum. The process involves the soaking of the parts in the presence of anhydrous ammonia at a temperature below the critical point of the steel. During the soaking period, the aluminum and iron combine with the nitrogen of the ammonia to produce iron nitrides in the surface of the metal. Warpage of work during nitriding can be reduced by stress-relief annealing, and by exposure to nitrogen at temperatures no higher than 1000°F (538°C). Growth of the work is similarly prevented, but cannot be entirely eliminated, and some parts may require special allowance in some dimensions to take care of growth.

The temperature required for nitriding is 950°F (510°C), and the soaking period from 48 to 72 hours. An airtight container must be used, and it should be provided with a fan to produce good circulation and even temperature throughout. No quenching is required, and the parts may be allowed to cool in air.

HEAT TREATMENT OF NONFERROUS METALS (ALUMINUM ALLOYS)

Aluminum is a white, lustrous metal, light in weight and corrosion resistant in its pure state. It is ductile, malleable, and nonmagnetic. Aluminum, combined with various percentages of other metals—generally copper, manganese, and magnesium—form the aluminum alloys that are used in aircraft construction. Aluminum alloys are lightweight and strong, but do not possess the corrosion resistance of pure aluminum and are generally treated to prevent deterioration. "Alclad" is an aluminum alloy with a protective coating of aluminum to make it almost equal to the pure metal in corrosion resistance.

Several of the aluminum alloys respond readily to heat treatment. In general, this treatment consists of heating the alloy to a known temperature, holding this temperature for a definite time, then quenching the part to room temperature or below. During the heating process, a greater number of the constituents of the metal are put into solid solution. Rapid quenching retains this condition, which results in a considerable improvement in the strength characteristics.

The heating of aluminum alloy should be done in an electric furnace or molten salt bath. The salt bath generally used is a mixture of equal parts of potassium nitrate and sodium nitrate. Parts heated by this method must be thoroughly washed in water after

treatment. The salt bath method of heating should never be used for complicated parts and assemblies that cannot be easily washed free of the salt.

Heat Treating Procedures

There are two types of heat treatment applicable to aluminum alloys. They are known as solution and precipitation heat treatment. Certain alloys develop their full strength from the solution treatment, while others require both treatments for maximum strength.

The NA 01-1A-9 lists the different temper designations assigned to aluminum alloys and gives an example of the alloys using these temper designations.

SOLUTION HEAT TREATMENT — The solution treatment consists of heating the metal to the temperature required to cause the constituents to go into a solid solution. To complete the solution, often the metal is held at a high temperature for a sufficient time, and then quenched rapidly in cold water to retain this condition. It is necessary that solution heat treatment of aluminum alloys be accomplished within close limits in reference to temperature control and quenching. The temperature for heat-treating is usually chosen as high as possible without danger of exceeding the melting point of any element of the alloy. This is necessary to obtain the maximum improvement in mechanical properties. If the maximum specified temperature is exceeded, eutectic melting will occur. The consequence will be inferior physical properties, and usually a severely blistered surface. If the temperature of the heat treatment is low, maximum strength will not be obtained.

PRECIPITATION (AGE) HARDENING — The precipitation treatment consists of "aging" material previously subjected to solution heat treatments by natural (occurs at room temperature) or artificial aging. Artificial aging consists of heating aluminum alloy to a specific temperature and holding for a specified length of time. During this hardening and strengthening operation, the alloying constituents in solid solution precipitate out. As precipitation progresses, the strength of the material increases until the maximum is reached. Further aging (overaging) causes the strength to decline until a stable condition is obtained. The strengthening of the material is due to the uniform alignment of the molecule structure of the aluminum and alloying element.

Artificially aged alloys are usually slightly "overaged" to increase their resistance to corrosion, especially the high copper content alloys. This is done to reduce their susceptibility to intergranular corrosion caused by underaging.

Natural aging alloys can be artificially aged; however, it increases the susceptibility of the material to intergranular corrosion. If used, it should be limited to clad sheet and similar items.

Quenching

The basic purpose for quenching is to prevent the immediate re-precipitation of the soluble constituents after heating to solid solution. To obtain optimum physical properties of aluminum alloys, rapid quenching is required. The recommended time interval between removal from the heat and immersion is 10 seconds or less. Allowing the metal to cool before quenching promotes intergranular corrosion and slightly affects the hardness. There are three methods employed for quenching. The one used depends upon the item, alloy, and properties desired.

COLD WATER QUENCHING — Small parts made from sheet, extrusions, tubing, and small fairings are normally quenched in cold water. The temperature before quenching should be 85°F or less. Sufficient cold water should be circulated within the quenching

tanks to keep the temperature rise under 20°F. This type of quench will ensure good resistance to corrosion, and is particularly important when heat-treating 2017 and 2024 alloys.

HOT WATER QUENCHING — Large forgings and heavy sections can be quenched in hot or boiling water. This type of quench is used to minimize distortion and cracking, which are produced by the unequal temperatures obtained during the quenching operation. The hot water quench will also reduce residual stresses, which improves resistance to stress corrosion cracking.

SPRAY QUENCHING — Water sprays are used to quench parts formed from alclad sheets and large sections of most alloys. Principal reasons for using this method are to minimize distortion and to alleviate quench cracking. This system is not usually used to quench bare 2017 and 2024 due to the effect on their corrosion resistance.

Annealing

Annealing serves to remove the strain hardening that results from cold working and, in the case of the heat-treated alloys, to remove the effect of the heat treatment. Annealing is usually carried out in air furnaces, but salt baths may be used if the melting point of the bath is low enough. A bath made up of equal parts by weight of sodium nitrate and potassium nitrate is satisfactory.

ANNEALING OF WORK HARDENED MATERIAL — Annealing of material that was initially in the soft or annealed condition but which has been strain-hardened by cold working, such as 1100, 3003, 5052, etc., is accomplished by heating the metal to a temperature of 660±10°F (349 ±5°C). It is only necessary to hold the metal at this temperature for a sufficient length of time to make certain that the temperature in all parts of the load has been brought within the specified range. If the metal is heated appreciably above 670°F (354°C), there is a partial solution of the hardening constituents, and the alloy will age harden while standing at room temperature unless it has been cooled very slowly. If the temperature is not raised to 650°F (343°C), the softening may not be complete. The rate of cooling from the annealing temperature is not important. However, a slow cool is desirable in case any part of the load may have been heated above the recommended temperature range.

ANNEALING OF HEAT-TREATED ALLOYS — The heat-treatable alloys are annealed to remove the effects of strain hardening or to remove the effects of solution heat treatment.

To remove strain hardening due to cold work, a 1-hour soak at 640° to 660°F, followed by air-cooling, is generally satisfactory. This practice is also satisfactory to remove the effects of heat treatment if the maximum of softness is not required.

To remove the effects of partial or full heat treatment, a 2-hour soak at 750° to 800°F, followed by a maximum cooling rate of 50°F per hour to 500°F, is required to obtain maximum softness.

To remove the effects of solution heat treatment or hardening due to cold work, the high zinc-bearing alloy 7075 should be soaked 2 hours at 775°F, air cooled to 450°F, and soaked 6 hours at 450°F. The stabilizing temperature at 450°F is necessary to precipitate the soluble constituents from solid solution.

The annealing of solution heat-treated material should be avoided whenever possible if subsequent forming and drawing operations are to be formed. If such operations are not severe, it is generally advantageous to repeat the solution heat treatment and form the material in the freshly quenched condition.

End of Chapter 6

NONDESTRUCTIVE INSPECTIONS, WELDING, AND HEAT TREATMENT

Review Questions

6-1. According to the NA-01-1A-16-1 and NA-01-1A-16-2, who can perform NDI inspections?

A. AM grade E-4 and above
B. Certified personnel only
C. Maintenance chief
D. Quality assurance technician

6-2. What type of examination must a candidate receive before being selected as an NDI inspector and annually thereafter?

A. Competency exam
B. Eye exam
C. Proficiency exam
D. Type aircraft written exam

6-3. If a technician is currently certified and engaged in NDI, what is the minimum amount of experience required in order for this technician to train and certify NDI operators?

A. 6 months
B. 1 year
C. 3 years
D. 5 years

6-4. What facilities conduct welding training and testing?

A. Aircraft division
B. Fleet Repair Center (FRC)
C. Naval Aviation Depot (NADEP)
D. Quality assurance

6-5. What is the recertification interval for IMA-level aeronautical equipment welders if proficiency is maintained?

A. 1 year
B. 2 years
C. 3 years
D. 4 years

6-6. If you fail the first test weld(s), what amount of time do you have to submit the retest welds after notification of failure?

A. 24 hours
B. 30 days
C. 6 months
D. 3 years

6-7. What is the only metal that cannot be hardened by heat-treatment?

A. Aluminum
B. Ferrous metals
C. Non-ferrous metals
D. Pure metal

6-8. Uneven heating of metal often causes what action(s) to occur?

A. Brittleness
B. Corrosion
C. Distortion and cracking
D. Warping

6-9. The slow heating of metal ensures what condition?

A. Corrosion resistance
B. Hardening
C. Normalizing
D. Uniformity