Weld Inspection

Integrity, safety & productivity through non-destructive testing solutions from GE’s Inspection Technologies business
Overview

A leading innovator for inspection solutions, GE delivers accuracy, productivity and safety to customers in a wide range of industries, including oil & gas, power generation, transportation and infrastructure.

Inspection Technologies advanced non-destructive testing (NDT) and imaging technologies utilize the electromagnetic, radiographic, ultrasonic or visible energy spectrum to examine a wide range of components. With extensive depth and breadth of knowledge, GE can help with a wide variety of specific application needs.

Weld Inspection

Welding is an essential manufacturing process performed in almost every major industry. Therefore, weld quality and integrity are critical to safety in an extremely wide range of products and structures.

Inspecting welds can also reduce costs by detecting discontinuities in the early stages of manufacturing, reducing the cost of rework and extending the life of components by detecting and correcting flaws. NDT methods can identify cracking, porosity, incomplete penetration, misalignment, inclusions, lack of fusion and similar conditions, which can compromise weld strength.

Multi-disciplinary Offering

- Ultrasonic flaw detectors and angle-beam transducers are commonly used for weld inspection and are mandated by many welding codes and procedures. Phased Array technology adds additional perspective to the image thereby simplifying interpretation of the test results by creating cross-sectional pictures of a weld, as well as offering beam-steering and dynamic-focusing capability.
- Radiographic solutions range from traditional X-ray generators and film to newer technologies such as Computed Radiography (CR), Direct Radiography (DR) and 3D Computed Tomography (CT).
- Electromagnetic Testing includes recent developments in 2D Eddy Current arrays and imaging of weld surfaces.
- Remote Visual Inspection, and the newer measurement techniques it brings, can significantly enhance weld inspection for many applications.

GE's Inspection Technologies business offers a comprehensive selection of testing and inspection capabilities and other products for industrial weld inspection applications. Our strength lies in the use of field experience and customer feedback to build productive inspection products. With a broad complement of non-destructive testing methods, our customers can be confident they are getting an optimized solution to meet their weld inspection needs.

DATA ➔ INFORMATION ➔ KNOWLEDGE ➔ DECISION

GE's NDT technologies help to collect important data and convert it into useful information. Coupled with historical plant data, intelligent software, image enhancement, databasing, applicable codes and additional knowledge, better informed decisions regarding weld integrity can be made.
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3D Computed Tomography (CT) of weld standard

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Electromagnetic Testing of weld surface

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2D Digital Radiograph of failed butt weld joint
The reliability and safe operation of Oil & Gas infrastructure is heavily dependent on the structural integrity of its welded joints. The quality of these joints must be assessed from the pipe mill and fabrication yard to the end of the operating life of the pressure vessel or piping system.

GE’s Inspection Technologies business continually strives to provide multi-disciplinary weld inspection solutions, whatever the application, whether onshore or offshore, in the field or in the factory.
Weld Inspection

**Upstream**
- Directional and crawler-compatible panoramic X-ray systems for pipeline girth-weld projects.

**Midstream**
- In-service welds can be examined with Electromagnetic Testing technology using the WeldScan ECT probe and instrument.
- Inspection systems using the latest Phased Array ultrasonic technology at a pipe mill.
- Weldstar is an automated ultrasonic inspection system for onshore or offshore pipeline girth-weld inspection using Phased Array and TOFD.

**Downstream**
- Co-Zoom PTZ cameras are used for downstream checks of refinery towers and storage tanks, avoiding manned entry.
- USM Go™ is a small, light and easy to use manual UT flaw detector effective for everyday use and difficult-to-access applications.
In the power generation sector, reliable and accurate non-destructive testing of welds and integrity assessment of boiler tubes are both essential in order to maximize efficiency, minimize downtime and improve productivity.

GE’s Inspection Technologies business offers a wide portfolio of support services and solutions for inspecting pipes, tubes and vessels, in manufacture, pre-service and in-service. These solutions use a variety of technologies to ensure that the inspection technique best matches the application, and finds application in fossil-fuel and nuclear stations as well as gas turbines, wind and hydro-electric assets.
Fossil Fuel

Digital Radiography for boiler pipe inspection at manufacturing stage as well as for in-service inspection.

RII video borecope image of weld inspection and sizing in a gas turbine.

Manual Phased Array UT inspection of a weld using Phasor™ XS and dual PA transducers.

PTZ camera and crawler for visual weld inspection on reactor head control rod guide tubes.

Semi-automated UT inspection using USM Vision™ for wind tower weld inspection.

Nacelle weld inspection with Phased Array UT flaw detector: Phasor™ XS.

Nuclear

Renewables
Aerospace Application Solutions

**Airframe Manufacturing**
- Small welded tube inspection with digital X-ray flat panel.
- Laser beam or friction stir weld inspection with Phasor™ XS.

**Engine Manufacturing**
- Aircraft engine inspection using the XLG3™ video borescope, an RVI solution.
- RVI of weld I.D. in fuel-supply lines.
- GE DXR 500 digital detector array for weld inspection.

**Maintenance, Repair & Overhaul**
- EC and EC Array blisk inspection (i.e. EC Array film for EC probe).
Automotive Application Solutions

Body Shell

- Ultrasonic inspection of spot welds using SpotChecker flaw detector.
- Microfocus CT slice across a 1 mm (0.039”) diameter weld.

Engines

- Visual inspection of difficult-to-access areas using video endoscopes.
- Fully automatic ultrasonic inspection of bonds in pistons and valves.

Safety Parts & Drivetrain

- Automatic 2D X-ray inspection of laser welds in safety parts.
- Microfocus CT slice across a laser weld interconnecting two inconel tubes with a steel cylinder.
Rail Application Solutions

**Rails**

- STH 1 is an ultrasonic rail testing system used to inspect rail welds (flash butt welds, alumino thermic welds) for discontinuity perpendicular to the rail surface.
- Ultrasonic inspection of butt welds using a roller probe.

**Locomotives**

- Inspection of draw gear butt welds using UT flaw detectors.
- Digital radiography weld inspection during construction of boogies.

**Rail Cars**

- Internal remote visual inspection of liquid-carrying rail car.
- PTZ camera image showing tank car interior details.
Phased Array weld inspection provides improved probability of detection and productivity.

USM Vision™ weld inspection solution for new process pipework fabrication inspection which eliminates downtime resulting from X-ray methods.

Completely light-tight, air-tight and moisture proof Pb VACUPAC™ film can be used for field weld inspection.

In-service radiographic inspection with the Eresco MF4 X-ray generator.

trueDGS™ probes offer increased accuracy in discontinuity sizing.

USM Go™ is a light weight and portable ultrasonic flaw detectors offering ease of use to detect, position and size discontinuities in welds.
Asset Life-Cycle Weld Inspection with Multi-Inspection Solutions

Weld inspection can be carried out using different NDT methods. GE offers multi inspection solutions for new project construction as well as for most project maintenance.

New Project Construction

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Rhythm Software

Acquire

Review

Archive
Post Project Maintenance

Inspection/Repair → Acceptance → Long-Term Storage

- Ultrasonic
- Electromagnetic Testing
- Radiography
- Remote Visual

Interpretation & Decision → Archive

Acquire → Review → Archive
Ultrasonic Testing (UT)

Ultrasonic techniques have been used in non-destructive testing for over 65 years, and apply to industrial applications requiring internal defect detection and sizing, including the inspection of welds.

Conventional Flaw Detectors
Portable flaw detectors and angle-beam transducers are commonly used for weld inspection and are mandated by many welding codes and procedures.

Phased Array Flaw Detectors
Phased Array technology simplifies result interpretation by creating cross-sectional and top view pictures of the weld. Beam-steering and focusing capability of Phased Array are key in enhancing resolution for challenging applications, resulting in faster weld inspections and better probability of detection.

Automated Girth-Weld Inspection System
Combining the benefits of both conventional and Phased Array ultrasonic techniques, the complete system approach offers automated ultrasonic inspection, from job setup to data archiving.

USM Go™ is a lightweight and portable ultrasonic flaw detector used to detect, position and size flaws in welds.

Phasor™ displays a cross section of the weld and allows the operator to display the A-scan associated with the optimum inspection angle.

The girth-weld pipe tester Weldstar has the ability to adjust for pipe diameters as small as 150 mm (6 inches).
USM Vision™
A total weld inspection solution to increase productivity in new process pipework fabrication

The USM Vision™ portable ultrasonic weld inspection system can be used in situations conventionally requiring radiography. The intuitive user interface and integration of the Rhythm™ Software platform optimizes available skills to achieve accurate and meaningful inspection results. It now has parallel-scanning capabilities, effectively doubling productivity.

Prepare
All that is required is to describe the inspection task, and enter the basic information such as site location, number of welds, pipe diameter, thickness and material, weld preparation, procedure and method to be used. The software will then calculate and generate all the UT set-ups required to perform TOFD and/or Phased Array inspection of the welds.

Collect
The inspection data for each weld is simply acquired by following the inspection plan and the different TOFD and PA passes calculated by the IPC (Inspection Plan Creator). After each pass the software will propose the next weld or pass to be inspected helping the operator to use the best, most productive inspection plan.

Analyze
All inspection data is communicated to an analysis station using the DICONDE-compliant Rhythm software platform. Here, the suitably qualified ultrasonic inspector can review and analyze the inspection data, utilizing advanced analysis tools such as real time, volume-corrected imaging, as well as conventional digital tools features for image analysis, enhancement and measurement.
Ultrasonic Testing Machines

Testing machines are integrated into production lines and are used to test a wide range of tubes and pipes. From small diameter, cold finished, seamless tubes (power plants or automotive industry) to large-diameter, heavy wall thickness, hot-rolled seamless tubes (casing and drill pipe and welded tubes for oil and gas pipelines).

Automated inspection of tubes and pipes

**UT HSAW (Helical submerged-arc welded)**
The base material for spiral-welded pipes is tested as strip before the forming rolls or at the tube after welding. The in-line weld testing takes place right after the welding and before pipe expansion. The final inspection, defined by the end-user specification, is carried out after the pressure test. Different probe arrangements adjacent to the weld and on the weld bead, are used to detect longitudinal and transverse flaws as well as lamination type flaws in the heat-affected zone (HAZ). All imperfections where the echo exceeds the adjusted threshold are processed automatically for flaw marking. Testing results are recorded in digital format and can be transferred to any second-level computer network.

**UT LSAW (Longitudinal submerged-arc welded)**
The plates for longitudinally welded pipes are typically tested in the plate mill. The weld is tested first time right after the last welding step and before mechanical expansion. The final inspection, defined by the end-user specification, is carried out after the hydrostatic test. Different probe arrangements in single probe mode or in tandem configuration are positioned adjacent to the weld or on the weld bead to detect longitudinal, transverse and lamination-type flaws in the heat-affected zone. Flaw evaluation and data processing is the same as for HSAW pipes.

**UT Phased Array**
Phased Array technology can be applied for all kinds of seamless and welded pipes (HSAW, LSAW, ERW). Single-crystal probes are replaced by multi-element probes with corresponding electronics. Phased Array technology supports a better probability of detection (POD) and an easier probe adjustment as a precondition for repeatability of testing results. By applying the ultrasonic Phased Array technology, different testing zones and angles can be created by electronic parameter setting. It is also possible that one Phased Array probe is used instead of multiple probe arrangements with complex mechanics.
UT/EC ERW (Electrical Resistance Welded)
The base material for ERW pipes is tested as strip before the forming stands. In a later phase the complete pipe body is tested similarly to a seamless pipe testing. The weld is tested in-line and after the welder or after the sizing stands because the pipe geometry can have an influence on the inspection. Typically probes are positioned adjacent to the weld for testing of longitudinal flaw orientations. The number of probes used depends on the thickness. In a later phase the complete pipe body is tested similarly to a seamless pipe.
Electromagnetic Testing (EM)

Electromagnetic Testing is a cost-effective, versatile and flexible non-destructive testing method. It has many advantages over other forms of inspection, including exceptional sensitivity to flaws at or near the surface, real-time results, documentation, elimination of the need to use chemicals, and additional environmental, health and safety (EHS) benefits.

Portable Flaw Detectors
Portable Electromagnetic Testing instruments are ideally suited for in-situ weld inspection. These compact, durable instruments can be used to inspect a variety of welded products with GE’s WeldScan probes. This inspection method is used to inspect oil platforms, cranes, ships and amusement park rides for weld cracking caused by cyclic fatigue, and can be accomplished through multiple layers of paint or coatings. Rope Access Inspectors find the equipment is extremely portable, cutting the costs of erecting access platforms. The inspection of welds is covered by Standard BS EN 1711-2000.

Probes
Weld inspection probes offer a cost-effective alternative to magnetic particle inspection for in-service inspection of welded steel structures. They can detect surface-breaking fatigue cracks through 2 mm (0.078") of surface coating material and are less expensive and quicker to use than any other method.

Array Probes
Electromagnetic Testing array technology can be an extremely useful tool for increasing productivity and detection capabilities for large surface areas including complex geometries. Typical surface inspection methods such as Dye Penetrant, require chemicals and processing time, whereas an Electromagnetic Testing technique can be done cleanly and nearly instantly.
Remote Visual Inspection (RVI)

RVI is a cost-effective inspection technique used to capture real-time views and images from inside tubes, pipes, rotating machinery, engines, heat exchangers, tray towers, refractory-lined vessels and enclosed structures. RVI can be a complementary technique to other NDT disciplines in the inspection of welds.

**Video Borescopes**
The use of video borescopes speeds up inspection time and provides sharp, clear illumination of surface-breaking weld attributes and defects. These instruments allow for the inspection of incomplete penetration of new welds inside a pipe and existing welds inside assembled components.

**Advanced Measurement & Imaging**
3D Phase Measurement provides accurate 3-dimensional surface scans allowing measurement of all aspects of surface indications. Inspectors can view and measure a defect using a single probe tip, eliminating the extra steps required to back out, change the tip and then relocate the defect. 3D Phase Measurement provides accurate measurement "on-demand" while simplifying the inspection process.

**Pan-Tilt-Zoom (PTZ) Cameras**
Industrial PTZ cameras can ideally be used for remote viewing in large areas. These systems feature a color zoom camera module, high-intensity lighting, pan-and-tilt mechanism and industrial waterproof packaging for protection from extreme environments.

Menu Directed Inspection (MDI) is software that runs on the video probe to guide an inspector through the inspection process. It standardizes the inspection workflow, saves time, reduces error, and creates consistent quality.

Cross-section of a weld showing the bead height.

Co-Zoom PTZ cameras are used for downstream checks of in-service welds in refinery towers and storage tanks, avoiding manned entry.
Radiographic Testing (RT)

Radiography is a proven and reliable non-destructive testing method. One of the main areas for the application of radiography is weld examination. GE has invested in all forms of imaging processes to ensure customers are free to choose the right technology for their application: film radiography, digital imaging including Computed Radiography (CR) and Direct Radiography (DR), industrial X-ray tubes and generators and 3D Computed Tomography (CT).

**Film Radiography**
Film systems are widely used for checking the integrity of welds and the circumstances in which these inspections take place are often very demanding. VACUPAC™ packed film is protected by a synthetic foil ensuring trouble free usage under dirty and damp conditions. ROLLPAC™ film in precut format, is ideal for pipeline projects with many pipes of the same diameter.

**Computed Radiography**
Although conventional film is still superior compared to the Computed Radiography technique, standards permit CR in several cases because it can provide sufficient image quality for weld inspection. Computed Radiography systems provide an overall imaging solution including imaging plates in specific weld sizes, scanners and weld inspection software.

**Direct Radiography**
At stationary locations the high performance Digital Detector Array (DDA) panels can image large numbers of components in a very short time due to the low dose requirements, coupled with automation or robotics. For field applications large format portable detectors bring significant image quality advantages coupled with their low dose requirements, especially important for control of radiation safety.

![ROLLPAC™ film packaging is completely light-tight and resistant to moisture and grease.](image1)

![CR’FLEX™ computed radiography scanner can be used in office, lab or field environments allowing imaging plates in various weld sizes to be scanned.](image2)

![DXR500L static digital detector array performing automated weld inspection achieves significant throughput achievements.](image3)
**Industrial X-ray Tubes & Generators**
160-300 kV portable and 160-450 kV stationary equipment with directional or panoramic tubes and different combinations of focal-spot sizes find application throughout the industrial spectrum of weld inspection.

**3D Computed Tomography (CT)**
Process control and optimization of laser and friction welding technologies require defect detection in the micron range. Additionally, for turbine or weld-seam inspection in tubes, a large variety of rod anodes for its microfocus X-ray tubes exist. Another important advantage of 3D Computed Tomography is that it shows the exact location, shape, orientation and size of the defect inside the sample.

**Rhythm™ Software**
Rhythm™ can acquire image data from CR and DR sources or from film digitizers. This data can be displayed on the monitor of a standard PC. Rhythm™ offers standardized reporting capability in easy-to-understand formats, with DICONDE-tagged images. This allows fast historical and meaningful comparison of reports from different inspections.
Reference Radiographs
The following selection of radiographs illustrates the wide variety of possibilities for detection of discontinuities.

Offset or mismatch (Hi-Lo).
An abrupt change in film density across the width of the weld image.

Offset or mismatch with Lack of Penetration (LOPI).
An abrupt density change across the width of the weld image with a straight longitudinal darker density line at the centre of the width of the weld image along the edge of the density change.

External concavity or insufficient fill.
The weld density is darker than the density of the pieces welded and extending across the full width of the weld.

Excessive penetration.
A lighter density in the centre of the width of the weld image, either extended along the weld or in isolated circular drops.
External undercut.
An irregular darker density along the edge of the weld image. The density will always be darker than the density of the pieces being welded.

Internal (root) undercut.
An irregular darker density near the centre of the width of the weld image and along the edge of the root pass image.

Internal concavity (suck back).
An elongated irregular darker density with fuzzy edges, in the vcentre of the width of the weld image.

Burn through.
Localized darker density with fuzzy edges in the centre of the width of the weld image. It may be wider than the width of the root pass image.

Incomplete - or Lack of Penetration (LoP).
A darker density band, with very straight parallel edges, in the center of the width of the weld image.

Interpass slag inclusions.
Irregularly-shaped darker density spot, usually slightly elongated and randomly spaced.
Radiographer’s Weld Interpretation Reference

- **Elongated slag lines (wagon tracks).**
  Elongated parallel or single darker density lines, irregular in width and slightly winding lengthwise.

- **Lack of side wall fusion (LOF).**
  Elongated parallel, or single, darker density lines sometimes with darker density spots dispersed along the LOF-lines which are very straight in the lengthwise direction and not winding like elongated slag lines.

- **Interpass cold lap.**
  Small spots of darker densities, some with slightly elongated tails in the welding direction.

- **Scattered porosity.**
  Rounded spots of darker densities random in size and location.

- **Cluster porosity.**
  Rounded or slightly elongated darker density spots in clusters with the clusters randomly spaced.

- **Root pass aligned porosity.**
  Rounded and elongated darker density spots that may be connected, in a straight line in the centre of the width of the weld image.
Transverse crack.
Feathery, twisting lines of darker density running across the width of the weld image.

Longitudinal crack.
Feathery, twisting line of darker density running lengthwise along the weld at any location in the width of the weld image.

Longitudinal root crack.
Feathery, twisting lines of darker density along the edge of the image of the root pass. The "twisting" feature helps to distinguish the root crack from incomplete root penetration.

Tungsten inclusions.
Irregularly shaped lower density spots randomly located in the weld image.
GE offers image review tools which enables smarter and quicker decisions in the field, factory floor or in the office. We offer software for all non-destructive testing (NDT) applications and methods, including software for data input, analysis, measurement, enhancement, review, documentation, data management, remote collaboration, and storage.

**Flash! Filters™ Image Enhancement**
Flash! Filters™ provide sharp views of weld images. As a plug-in module for the Rhythm™ Review software, the clarity of the images significantly increases flaw detection while minimizing image analysis time. Flash! Filters™ is able to quickly edge-enhance and improve digital images into film-like images.
- No Windows leveling
- Streamlined workflow
- Sharper images

**Reporting and Advanced Reporting**
The automated report generator tools allow creation of customized report of findings. Users are able to create their own unlimited number of report formats and can automatically populate them with DICONDE data.

**Rhythm™ Enterprise Archive**
Rhythm™ Enterprise Archive delivers a complete, scalable and flexible central archiving DICONDE* (the industry-accepted protocol solution for non-destructive testing images and information. One platform to use to centrally store all data (Visual, Electromagnetic, Radiographic, and Ultrasonic). Advanced data sharing and fast retrieving capabilities allow significant improvements in productivity and enable faster identification of quality problems.

GE’s Rhythm Software plays a key role in enabling asset owners to integrate NDT data and other information with additionally available knowledge in order to make well-informed decisions regarding plant components and their remaining life.

* DICONDE: Digital Imaging and Communication in non-destructive evaluation (first ASTM release in 2004)
**Rhythm™ Review**

Rhythm™ Review accepts data from Rhythm Acquire, other Rhythm™ Review workstations, and removable media, such as CDs and DVDs. It provides application tools for analysis, enhancement, measurement, reporting and storage of received data.

**Rhythm™ Enterprise Web**

Rhythm™ Enterprise Web provides on-demand access to NDT inspection data maintained in a central Rhythm™ Enterprise Archive server with just a web browser and login information. Rhythm™ Enterprise Web brings DICONDE viewing capabilities to the internet and provides a convenient distribution engine with web-based functionality.

Remote expert review and analysis, as information can be shared between networked Review workstations with no limit to file size.

Rhythm™ Web allows for optimal delivery of multi-disciplinary NDT images and reports to all users.
Weld Types

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**Weld Inspection**

**Base metal**
- Shielded or heavy coating
- Electrode core wire
- Gaseous shield
- Molten weld metal
- Weld deposited
- Slag
- Projecting sheath
- Crater

**Penetration**
- Tungsten Inert Gas (TIG)
  - Stainless steel, non-ferrous materials, aluminum, magnesium
  - Aerospace and space vehicles, nuclear applications, thin wall materials manufacturing applications
  - Fabrication shop, factory
  - Stronger, higher quality welds
  - Used with thin materials
  - Greater operator control over the weld
  - Highly resistant to corrosion and cracking

- Manual Metal Arc - MMA (MMA)
  - Iron and steel, stainless steel, aluminum, nickel, copper alloys
  - Steel structures, industrial fabrication

- Submerged Arc (SAW)
  - Carbon steel, stainless steel, nickel-based alloys, low alloy steel, surfacing applications (i.e. weld buildup)
  - Structural and vessel construction, pipes

**Advantages**
- Low equipment costs and wide applicability
- Dominant process in repair and maintenance
- Basically no thickness limitations
- Can be used in almost any position

**Limitations**
- Applications are limited by welder skill
- Potential safety issues if not monitored
- Applications may require preheat

**Typical Discontinuities Types**
- Porosity, lack of fusion, incomplete penetration, and cracks

**Non-destructive Testing Methods**
- Visual Testing ................ VT
- Penetrant Testing .............. PT*
- Magnetic Particle Testing ...... MT*
- Radiographic Testing .......... RT**
- Ultrasonic Testing .............. UT***
- Eddy Current Testing .......... ET***

* For surface discontinuities
** For subsurface discontinuities
*** For surface-breaking discontinuities and usually used to supplement PT, MT

**Applications**
- Steel structures, industrial fabrication

**Typical Location**
- Fabrication shop, factory
- Field operations
- Suitable for indoor or outdoor use

**Typical Location**
- Fabrication shop, factory
- Field operations
- Suitable for indoor or outdoor use

**Advantages**
- Stronger, higher quality welds
- Used with thin materials
- Greater operator control over the weld
- Highly resistant to corrosion and cracking

**Limitations**
- Cannot be used on lead or zinc
- Economically not feasible for steel
- Slower production and difficult to master

**Typical Discontinuities Types**
- Porosity, lack of fusion, incomplete penetration, and cracks

**Non-destructive Testing Methods**
- Visual Testing ................ VT
- Penetrant Testing .............. PT*
- Magnetic Particle Testing ...... MT*
**Resistance Spot Weld (RSW)**

**Materials**
Sheet metal, aluminum alloys

**Applications**
Automotive, weld studs and nuts to metal, weld screw machine parts to metal, join cross wires and bars

**Typical Location**
Fabrication shop, factory

**Advantages**
- Limits the areas of excessive heating
- Energy controlled - more reliable welds
- Allows closer spacing of welds
- A production process can be completely automated

**Limitations**
- Tends to harden the material
- Reduce fatigue strength
- Stretch or anneal the material
- Cause the material to warp

**Typical Discontinuities Types**
- Cracks, porosity and expulsion

**Non-destructive Testing Methods**
- VT, UT

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**Gas Metal Arc – GMAW**

**Metal Inert Gas – MIG**

**Structural steel - aluminum sections – stainless steel and nickel alloys - some offshore applications**

**Applications**
Automotive, structural, ornamental

**Advantages**
- Fabrication shop, factory - field applications
- Versatility and speed
- Adaptive to robotic automation
- No shielding gas is required making it suitable for outdoor welding and/or windy conditions
- High-deposition rate process
- Less precleaning of metal required
- The weld metal is protected initially from external factors until the flux is removed

**Limitations**
- Limited to indoor use
- Unusable underwater
- Weld quality can fluctuate

**Typical Discontinuities Types**
- Dross and porosity, lack of fusion, excessive penetration, silica inclusions, cracking, undercut

**Non-destructive Testing Methods**
- RT, UT

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**Flux-Cored Arc Weld (FCAW)**

**Materials**
- Mild- and low-alloy steels, stainless steels, some high nickel alloys

**Applications**
Automotive, structural steels

**Advantages**
- Factory or field
- No shielding gas is required making it suitable for outdoor welding and/or windy conditions
- High-deposition rate process
- Less precleaning of metal required
- The weld metal is protected initially from external factors until the flux is removed

**Limitations**
- When the electrode contacts the base metal, the contact tip can melt fusing it to the base metal
- Irregular wire feed – usually the result of a mechanical problem
- More costly filler material/wire than GMAW

**Typical Discontinuities Types**
- Porosity, lack of fusion, inclusions, incomplete penetration, hollow bead and cracks. Also, overlap, weld spatter, underfill, and undercut.

**Non-destructive Testing Methods**
- VT, PT, MT, RT, UT

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**Visual Testing**
- VT *

**Penetrant Testing**
- PT *

**Magnetic Particle Testing**
- MT *

**Radiographic Testing**
- RT **

**Ultrasonic Testing**
- UT **

**Eddy Current Testing**
- ET ***

* For surface discontinuities
** For subsurface discontinuities
*** For surface-breaking discontinuities and usually used to supplement PT, MT
### Laser Beam
**LBW**

- **Materials**: Carbon steel, stainless steel, aluminum, titanium
- **Applications**: Automotive, aerospace
- **Typical Location**: Factory
- **Advantages**: Versatile process - high quality yield
- **Limitations**: Cracking with hi-carbon steels
- **Discontinuities**: Porosity, cracks, lack of fusion
- **Testing Methods**: VT, PT, MT, RT, UT

### Electron Beam
**EBW**

- **Materials**: Stainless steel, superalloys, refractory metals
- **Applications**: Aerospace and automotive, semiconductor
- **Typical Location**: Manufacturing facility
- **Advantages**: Has a very small heat affected zone
- **Limitations**: Lack of penetration, lack of fusion, cracking
- **Discontinuities**: Incomplete penetration, lack of fusion, cracks and porosity
- **Testing Methods**: VT, PT, MT, RT, UT

### Brazing

- **Materials**: Copper, brass, bronze, aluminum and others
- **Applications**: Electrical, electronics, transportation, appliances, and construction
- **Typical Location**: Manufacturing / field - indoors or outdoors
- **Advantages**: Easy to learn, virtually any dissimilar metal can be joined, the bond line can be very neat in appearance, and the joint strength is strong enough for most non-heavy-duty use applications.
- **Limitations**: A badly brazed joint can look similar to a good joint, and can have a very low strength. The metal used to bond the two parts may be different in color than the parts being bonded. Long-term effects of dissimilar metals in constant contact may need to be examined for special applications. Since the filler material (typically bronze) melts at a relatively low temperature, brazed parts should not be put in an environment which exceeds the melting point of the filler metal.
- **Discontinuities**: Lack of fill (unbond), porosity, cracks, and cold bond
- **Testing Methods**: VT, PT, UT
**Soldering**

- **Materials**
  - Copper, silver, gold, iron, nickel
  - Electronic components, pipe soldering, aluminum, stained glass

- **Applications**
  - Round / square tubing
  - Ship building and offshore - aerospace and automotive - railway rolling stock - specialized fabrication

- **Typical Location**
  - Manufacturing / field - indoors or outdoors

- **Advantages**
  - Soldering can be manual or automated
  - Formulated for maximum electrical conductivity
  - High production - easy automation
  - Energy efficient
  - Typically stronger than the material itself
  - Very durable weld
  - Can be used on large pieces not post weld heat treated
  - Used where metal characteristics must remain unchanged
  - Low concentration of discontinuities
  - Can operate in all positions
  - Minimum safety issues / low environment impact

- **Limitations**
  - Soldering difficulty can increase when other materials are involved
  - Power source and material thickness must match

- **Typical Discontinuities**
  - Cold solder joint, oxidation, cracks and voids
  - Pin holes, cracks

- **Non-destructive Testing Methods**
  - VT

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**Electric Resistance ERW**

- **Steel**

- **Manufacturing**
  - High production - easy automation
  - Energy efficient

- **Advantages**
  - Typically stronger than the material itself
  - Very durable weld
  - Can be used on large pieces not post weld heat treated
  - Used where metal characteristics must remain unchanged
  - Low concentration of discontinuities
  - Can operate in all positions
  - Minimum safety issues / low environment impact

- **Limitations**
  - Power source and material thickness must match

- **Typical Discontinuities**
  - Pin holes, cracks

- **Non-destructive Testing Methods**
  - VT, PT, RT

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**Friction Stir FSW**

- **Aluminum - copper**

- **Applications**
  - Ship building and offshore - aerospace and automotive - railway rolling stock - specialized fabrication

- **Advantages**
  - Fabrication shop, factory

- **Limitations**
  - Exit hole left when tool is withdrawn
  - Heavy duty clamping necessary
  - Less flexible and often slower

- **Typical Discontinuities**
  - Cracks and lack of penetration, kissing bonds

- **Non-destructive Testing Methods**
  - UT, PT

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**Visual Testing**

- VT

**Penetrant Testing**

- PT

**Magnetic Particle Testing**

- MT

**Radiographic Testing**

- RT

**Ultrasonic Testing**

- UT

**Eddy Current Testing**

- ET

* For surface discontinuities
** For subsurface discontinuities
*** For surface-breaking discontinuities and usually used to supplement PT, MT
### Fusion Bonding
- **Materials**: Composites, stainless steels, alloys, ceramics
- **Applications**: Aerospace
- **Typical Location**: Manufacturing
- **Advantages**: Creates a bond by atomic attraction
  - Used with MEMS fabrication / silicon
  - No other materials required in the process
  - Alternative to glue, screws or snap fit
  - Easily automated
  - Clean, precise joints
  - Used for electrical wire harness connections
- **Limitations**: Must be highly polished, clean surfaces
  - Low strength improved by thermal treatment
- **Typical Discontinuities Types**: Laminations, lack of bonding

### Ultrasonic
- **Materials**: Composites, plastics, dissimilar materials
- **Applications**: Aerospace, automotive, medical, computer, packaging
- **Typical Location**: Manufacturing
- **Advantages**: No other materials required in the process
  - Alternative to glue, screws or snap fit
  - Easily automated
  - Clean, precise joints
  - Used for electrical wire harness connections
- **Limitations**: Only used for small welds
  - Major limitation is material thickness
  - Limited by the amount of power available
- **Typical Discontinuities Types**: Determine the presence of unbonds

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*Visual Testing* .............. VT *
*Penetrant Testing* ............. PT*
*Magnetic Particle Testing* .... MT*
*Radiographic Testing* ........... RT**
*Ultrasonic Testing* ............. UT**
*Eddy Current Testing* .......... ET***

* For surface discontinuities
** For subsurface discontinuities
*** For surface-breaking discontinuities and usually used to supplement PT, MT
Weld Inspection is required for all welds. Radiographic Testing or Ultrasonic Testing is required if the temperature exceeds 750°F or if the temperatures are between 350°F and 750°F with pressures over 1025 psig.

ASME B31.2 ....................... Fuel Gas Piping

 Applies to piping systems for fuel gases. These gases include manufactured gas, liquefied petroleum gas, natural gas, and mixtures above the upper combustible limits. The piping systems that are covered by this code maybe be in or between buildings from the meter set to the first pressure containment valve.

ASME B31.3 ....................... Process Piping

This code covers piping in chemical plants. The quality of the weld is set by the owner's determination of the safety aspects of the fluid being contained.

ASME B31.4 ..................... Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids

This code covers piping for liquid petroleum products such as crude oil and gasoline.

ASME B31.5 ...................... Refrigeration Piping and Heat Exchanger Components

This code applies to refrigerant and brine piping systems. It does not include self-contained or unit refrigeration systems that are subject to UL specifications.

ASME B31.8 ............... Gas Transmission and Distribution Piping Systems

Applies to regulating stations, gas compressor stations, gas mains and service lines up to the end users meter set.

ASME B31.9 ....................... Building Services

Covers building services for heating and cooling water, condensing water, steam, vacuum, compressed air, combustible liquids and non-flammable gases. Boiler external piping has a max of 15 psig for steam boilers and for water heating units the max is 160 psig and 250°F. There is a maximum size for materials. For example carbon steel can not exceed 30” NPS or 0.50” wall. All welds must be VT although 100% penetrant is not required.
AWS D1.5 .......................... Bridge Welding Code
This code covers the welding fabrication requirements applicable to
welded highway bridges. The Code does not apply to steels that are less
than 3mm in thickness.
AWS D1.6 .......................... Structural Welding Code - Stainless Steel
This Code applies to the welding of structural stainless steel.
AWS D1.7 .......................... Structural Welding Code - Strengthening
and Repair
AWS D1.8 .......................... Structural Welding Code - Seismic Supplement
AWS D1.9 .......................... Structural Welding Code - Titanium
AWS D8.1 .......................... Automotive Spot Welding Code
AWS D8.6 .......................... Automotive Spot Welding Electrodes
Supplement
AWS D8.7 .......................... Automotive Spot Welding Recommendations
Supplement
AWS D8.8 .......................... Automotive Arc Welding (Steel) Code
AWS D8.9 .......................... Automotive Spot Weld Testing
AWS D9.1 .......................... Sheet Metal Welding Code
AWS D10.10 ........................ Heating Practices for Pipe and Tube
AWS D10.11 ........................ Root Pass Welding for Pipe
AWS D10.12 ........................ Pipe Welding (Mild Steel)
AWS D10.13 ........................ Tube Brazing (Copper)
AWS D10.18 ........................ Pipe Welding (Stainless Steel)
AWS D11.2 .......................... Welding (Cast Iron) Code
AWS D14.1 .......................... Industrial Mill Crane Welding
AWS D14.3 .......................... Earthmoving & Agricultural Equipment Welding
AWS D14.4 .......................... Machinery Joint Welding
AWS D14.5 .......................... Press Welding Code
AWS-D14.6 .......................... Industrial Mill Roll Surfacing
AWS D15.1 .......................... Railroad Welding Code
AWS D15.2 .......................... Railroad Welding Practice Supplement
AWS D16.1 .......................... Robotic Arc Welding Safety
AWS D16.2 .......................... Robotic Arc Welding System Installation
AWS D16.3 .......................... Robotic Arc Welding Risk Assessment
AWS D16.4 .......................... Robotic Arc Welder Operator Qualification
AWS D17.1 .......................... Aerospace Fusion Welding
AWS D17.2 .......................... Aerospace Resistance Welding
AWS D18.1 .......................... Hygienic Tube Welding (Stainless Steel)
AWS D18.2 .......................... Stainless Steel Tube Discoloration Guide
AWS D18.3 .......................... Hygienic Equipment Welding

American Society for Testing and Materials (ASTM codes)

Examination
E114-10 .......................... Standard Practice for Ultrasonic Pulse-Echo
Straight-Beam Contact Testing
E164-08 .......................... Standard Practice for Contact Ultrasonic
Testing of Weldments
E165-09 .......................... Standard Practice for Liquid Penetrant
Examination for General Industry
E213-09 .......................... Standard Practice for Ultrasonic
Testing of Metal Pipe and Tubing
E273-10 .......................... Standard Practice for Ultrasonic Testing
of the Weld Zone of Welded Pipe and Tubing
E309-11 .......................... Standard Practice for Eddy-Current
Examination of Steel Tubular Products
Using Magnetic Saturation
(Eddy-Current) Examination of Seamless
and Welded Tubular Products, Austenitic
Stainless Steel and Similar Alloys
E566-09 .......................... Standard Practice for Electromagnetic
(Eddy-Current) Sorting of Ferrous Metals
E587-10 .......................... Standard Practice for Ultrasonic
Angle-Beam Contact Testing
E703-09 .......................... Standard Practice for Electromagnetic
(Eddy-Current) Sorting of Nonferrous Metals
E709-08 .......................... Standard Guide for Magnetic
Particle Testing

American Petroleum Institute (API Codes)

API Standard 1104 .......................... Welding Pipelines and
Related Facilities
API Standard 620 .......................... Design and Construction of Large,
Welded, Low Pressure Storage Tanks
API Standard 653 .......................... Tank Inspection, Repair, Alteration
and Reconstruction
API Standard 650 .......................... Welded Steel Tanks for Oil Storage
API Spec 5L .......................... Specification for Line Pipe
API Spec 6D .......................... Specification for Pipeline Valves
Codes, Standards, Regulations & Recommended Practices

E797/E797M-10 ........... Standard Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo Contact Method
E999-10 ............. Standard Guide for Controlling the Quality of Industrial Radiographic Film Processing
E1032-06 ............. Standard Test Method for Radiographic Examination of Weldments
E1065-08 ............. Standard Guide for Evaluating Characteristics of Ultrasonic Search Units
E1212-09 ........... Standard Practice for Quality Management Systems for Non-Destructive Testing Agencies
E1255-09 ............. Standard Practice for Radioscopy
E1316-11a ............ Standard Terminology for Non-Destructive Examinations
E1411-09 ............. Standard Practice for Qualification of Radioscopic Systems
E1416-09 ............. Standard Test Method for Radioscopic Examination of Weldments
E1417-05e1 ........... Standard Practice for Liquid Penetrant Testing
E1441-11 ............. Standard Guide for Computed Tomography (CT) Imaging
E1444-05 ............. Standard Practice for Magnetic Particle Testing
E1570-11 ............. Standard Practice for Computed Tomographic (CT) Examination
E1742/E1742M-11 ............. Standard Practice for Radiographic Examination
E1815-08 ............. Standard Test Method for Classification of Film Systems for Industrial Radiography
E1901-08 ............. Standard Guide for Detection and Evaluation of Discontinuities by Contact Pulse-Echo Straight-Beam Ultrasonic Methods
E2192-08 ............. Standard Guide for Planar Flaw Height Sizing by Ultrasonics
E2373-09 ............. Standard Practice for Use of the Ultrasonic Time of Flight Diffraction (TOFD) Technique
E2375-08 ............. Standard Practice for Ultrasonic Testing of Wrought Products
E2662-09 .......... Standard Practice for Radiologic Examination of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications
E2663-08 .......... Standard Practice for Digital Imaging and Communication in Non-Destructive Evaluation (DICONDE) for Ultrasonic Test Methods
E2698-10 ............. Standard Practice for Radiological Examination Using Digital Detector Arrays
E2700-09 ........... Standard Practice for Contact Ultrasonic Testing of Welds Using Phased Arrays
E2736-10 ............. Standard Guide for Digital Detector Array Radiology

Canada

Canadian Standards Association (CSA Codes)

CSA W47.1 ........... Certification of Companies for Fusion Welding of Steel
CSA W59 ........... Welded Steel Construction (Metal Arc Welding)
CSA W59.2 ............ Welded Aluminum Construction
Europe

European Welding Standards

EN ISO 5817 ........... Welding – Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) – Quality levels for imperfections
EN ISO 6520-1/2 ....... Welding and allied processes – Classification of geometric imperfections in metallic materials – Parts 1 and 2
EN ISO 6520-2
EN ISO 10863 ............ Non-destructive testing of welds – Use of time-of-flight diffraction technique (TOFD)
EN ISO 10893-112 ....... Non-destructive testing of steel tubes – Parts 1-12
EN ISO 10893-12
EN ISO 11666 ........... Non-destructive testing of welds – Ultrasonic testing of welded joints – Acceptance levels
prEN ISO 12932 ....... Welding – Laser-arc hybrid welding of steels, nickel and nickel alloys – Quality levels for imperfections
prEN ISO 13588 ....... Non-destructive testing of welds – Ultrasonic testing – Use of automated Phased Array technology
EN ISO/NP 17405 ....... Non-destructive testing – Ultrasonic testing - Technique of testing claddings produced by welding, rolling and explosion
EN ISO 17635 ......... Non-destructive testing of welds – General rules for metallic materials
prEN ISO 17636-1 .... Non-destructive testing of welds – Radiographic examination of welded joints – Part 1: Industrial films
prEN ISO 17636-2 .... Non-destructive testing of welds – Radiographic examination of welded joints – Part 2: Imaging plates
EN ISO 17637 ......... Non-destructive testing of welds – Visual testing of fusion-welded joints
EN ISO 17638 ....... Non-destructive testing of welds – Magnetic particle testing
EN ISO 17640 ....... Non-destructive testing of welds – Ultrasonic testing – Testing levels, and assessment
prEN ISO 19232-15 .... Non-destructive testing – Image quality of radiographs – Parts 1-5: Image quality indicators (wire type) – Determination of image quality value
FprEN ISO 22825 ....... Non-destructive testing of welds – Ultrasonic testing – Testing of welds in austenitic steels and nickel-based alloys
EN ISO 23277........... Non-destructive testing of welds – Penetrant testing of welds – Acceptance levels
EN ISO 23278 ........ Non-destructive testing of welds – Magnetic particle testing of welds – Acceptance levels
EN ISO 23279 ......... Non-destructive testing of welds – Ultrasonic testing – Characterization of indications in welds
EN ISO 25239-5 ...... Friction stir welding – Aluminium – Part 5: Quality and inspection requirements

ISO and European standards for non-destructive testing of welds

EN 1435 ......... Non-destructive examination of welds – Radiographic examination of welded joints
EN 4678 ............. Aerospace series - Weldments and brazements for aerospace structures - Joints of metallic materials by laser beam welding – Quality of weldments – Bilingual version
EN 12517-1 ....... Non-destructive testing of welds – Part 1: Evaluation of welded joints in steel, nickel, titanium and its alloys by radiography – Acceptance levels
EN 12517-2 ....... Non-destructive testing of welds – Part 2: Evaluation of welded joints in aluminium and its alloys by radiography – Acceptance levels
EN 12952-6 ......... Water-tube boilers and auxiliary installations – Part 6: Inspection during construction, documentation and marking of pressure parts of the boiler
prEN 13445-5 ....... Unfired pressure vessels – Part 5: Inspection and testing
EN 13480-5 ......... Metallic industrial piping – Part 5: Inspection and testing
Codes, Standards, Regulations & Recommended Practices

Japan

Japanese Welding Standards (WES)

WES 7101 ........... Welding Position and Range of Plate Thickness for Qualified Welder
WES 7102 ........ Recommended Practices for Inert Shielded Arc Welding (Titanium and Titanium alloy)
WES 7103 ........ Recommended Practice for Oxyacetylene Welding of Cast Iron
WES 7014 ........ Recommended Practice for Arc Welding of Cast Iron
WES 7105 ........ Recommended Hard Facing Practice with Shielded Metal Arc Welding
WES 7301 ........ Recommended Practice for Spot Welding (Low Carbon Steel and Low Alloy Steel)
WES 7302 ........ Recommended Practice for Spot Welding (Aluminum and Aluminum Alloy)
WES 7303 ........ Recommended Practice for Spot Welding (Stainless Steel)
WES 7601 ........ Recommended Practice for Field Welding of Foundation Piles
WES 7602 ........ Recommended Practices for Inert Gas Shielded Arc Welding of Titanium Clad Steel and for Titanium Lining
WES 8101 ........ Standard for Certification of Fillet Welding Operator
WES 8102 ........ Welder Performance Qualification (For Petroleum Industry)
WES 8103 ........ Standard for Certification of Welding Coordination Personnel
WES 8105 ........ Standard for Certification of Welding Operator of PC Steel Rods
WES 8106 ........ Standard for Certification of Welding Operator of Foundation Piles
WES 8107 ........ Standard for Certification of Welding Practitioner
WES 8109 ........ Standard for Certification of Micro-Soldering Personnel
WES 8110 ........ Standard Qualification Procedure for Robot Welding Operators of Building Structures
WES 8111 ........ Certification Procedure for Robot Welding Operators of Building Structures
WES 8201 ........ Standard for Certification of Manual Arc Welding Operator
WES 8205 ........ Standard for Certification of Titanium Welding Operator
WES 8207 ........ Standard for Certification of Welders and Welding Operators for Power Plant Equipment
WES 8217 ........ Standard for Certification of Welding Procedure for Power Plant Equipment
WES 8221 ........ Certification Procedure of Welders of Stainless Steels
WES 8231 ........ Certification Procedure of Welders of Plastics
WES 8241 ........ Standard for Certification of Semi-automatic Welding Operator
WES 8291 ........ Certification Procedure for Operators of Silver Alloy Brazing
WES 8302 ........ Certification Test Manual of Welders for the Processing Facility and Re-processing Facility Based on the Reader Regulation Law
WES 8312 ........ Certification Test Manual of Welding Procedure for the Processing Facility and Re-processing Facility based on the Reactor Regulation Law
WES 8701 ........ Standard for Certification of Non-destructive Inspection Enterprise for Welded Structures
WES 8703 ........ Standard Qualification Procedure for Welding Robots for Building Structure
WES 8704 ........ Certification Procedure for Welding Robots of Building Structures
WES 8705 ........ Guideline for Accreditation of Non-destructive Testing Enterprise
WES 8706 ........ Standard of Registration of Personnel in Non-destructive Testing Enterprise for Welded Construction
China

Chinese Welding Standards
(GB Standards or Recommendations)

GB/T 12467 ...........Fusion Welding of Metallic Materials
GB/T 15169 ...........Qualification Test of Welders - Fusion for Welding Steels
GB 50235-97 ...........Chemical Metal Pipe Construction and Acceptance
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