

TRAINING MANUAL

FABRICATION AND WELDING ENGINEERING

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The bi-annual training and testing records have been included separately along with the individuals' certificates.

We hope you enjoyed training with us and hope to see you again in the future.

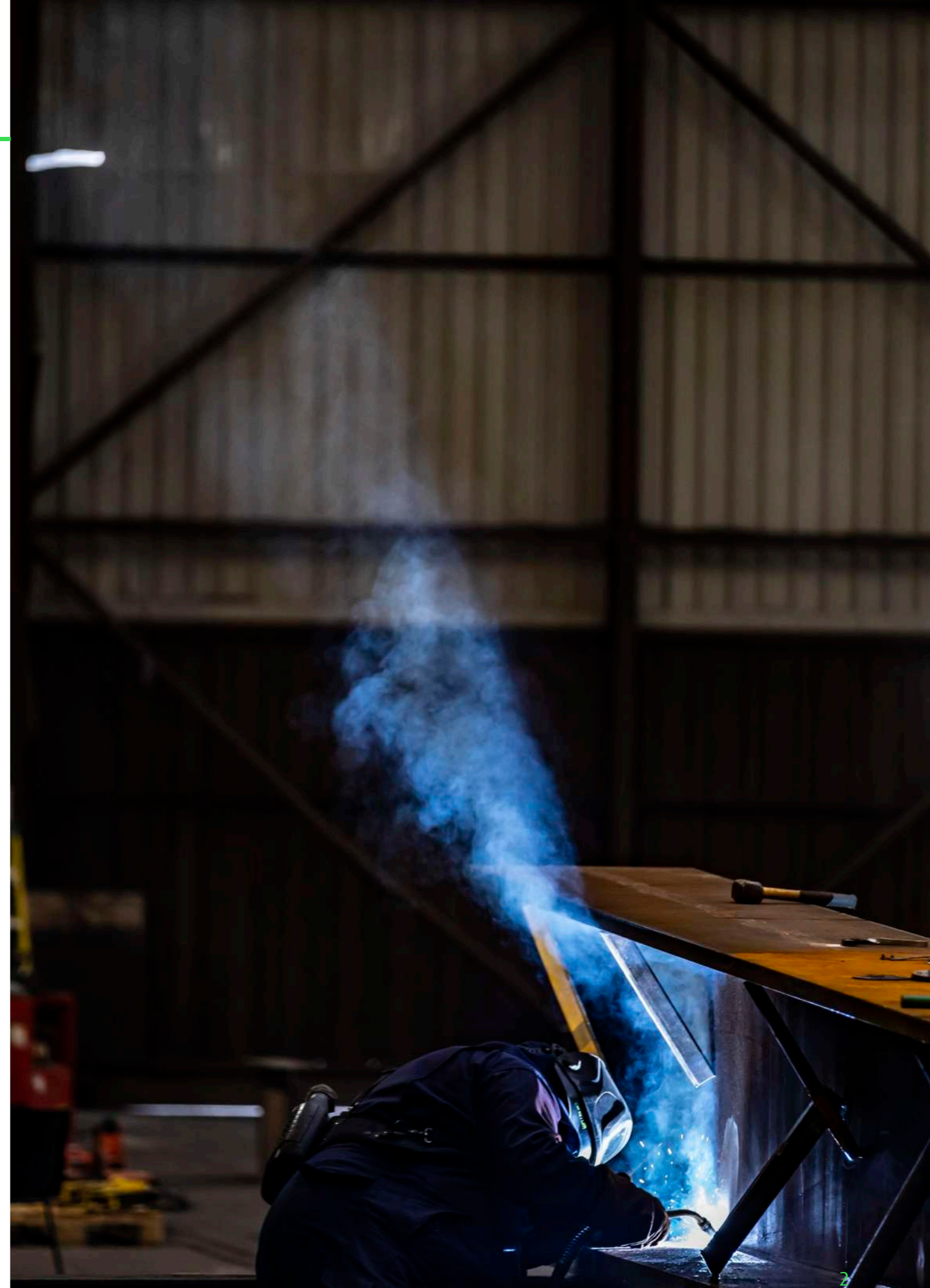
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INTRODUCTION

Welcome to our welding training manual! This manual has been designed to provide you with a comprehensive understanding of welding, including the different types of metals used in welding, how to identify defects, and non-destructive testing (NDT) practices.

Welding is a critical process in many industries, from manufacturing to construction. It involves the joining of two or more metal components by heating and melting them together, creating a permanent bond between them. Welding requires a high degree of skill and precision, as well as an understanding of the different types of metals used in welding, and the various defects that can occur during the welding process.

This training manual is divided into several sections, each providing you with a detailed overview of various aspects of welding.

Section 1

Will cover the different types of metals used in welding, including carbon steel, stainless steel, and aluminium. We will also explore the properties of these metals and how they affect the welding process.

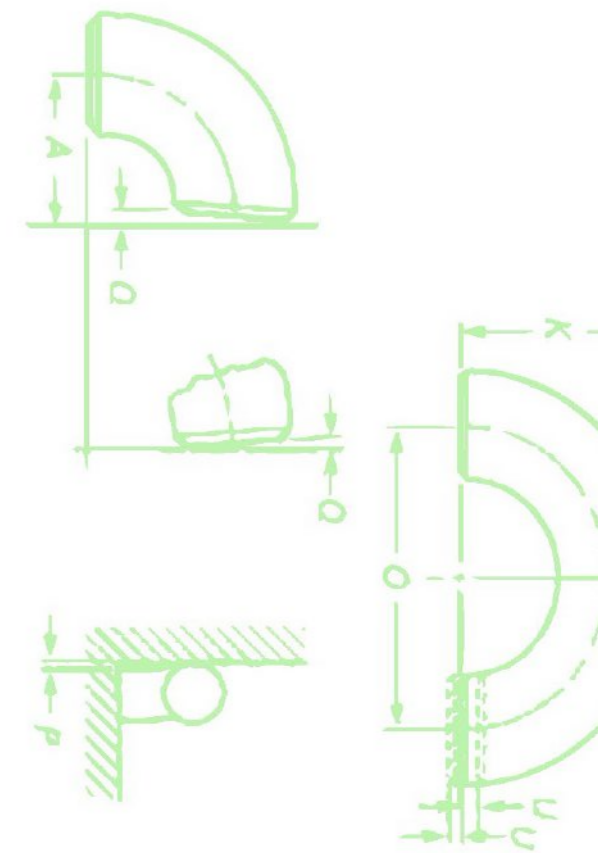
Section 2

Will focus on how to identify defects in welded joints. Welding defects can be caused by a variety of factors, including poor workmanship, incorrect welding techniques, or inadequate preparation of the metal surfaces. It is essential to be able to identify these defects and take appropriate corrective action to ensure the integrity of the finished product.

Section 3

Will provide an introduction to non-destructive testing (NDT) practices in welding. NDT is an essential part of the welding process, allowing welders to identify defects and ensure that the finished product meets the required standards. We will explore the different types of NDT techniques used in welding, including radiographic testing, ultrasonic testing, and magnetic particle testing.

Throughout this training manual, we will provide you with practical examples, detailed illustrations, and step-by-step instructions to help you develop your welding skills and knowledge. We hope that you find this manual informative and engaging, and that it helps you to become a skilled and knowledgeable welder.



CARBON STEELS

Carbon steel is a type of steel that contains carbon as the primary alloying element. It is one of the most widely used materials in the manufacturing industry due to its durability, strength, and affordability. Carbon steel is produced by melting iron ore and mixing it with carbon at high temperatures, resulting in a material that can be moulded into a variety of shapes.

The carbon content in carbon steel can range from 0.05% to 2.0%, with the amount of carbon determining the steel's properties. Low carbon steel contains less than 0.30% carbon and is typically used in applications that require high ductility and toughness, such as construction materials or car parts. Medium carbon steel contains between 0.30% and 0.60% carbon and is often used in the production of machinery and tools. High carbon steel contains more than 0.60% carbon and is commonly used in the manufacturing of cutting tools, springs, coils, washes and fasteners.

All of our training courses use MMA, TIG, MIG / MAG and FCAW welding procedures qualified to ISO 15614 – and all graduates are qualified to ISO 9606.

One of the key advantages of carbon steel is its versatility. Carbon steel can be alloyed with other elements, such as manganese or nickel, to improve its strength or corrosion resistance. Carbon steel can also be heat-treated to enhance its hardness or ductility, making it suitable for a wide range of applications.

Another advantage of carbon steel is its affordability. Carbon steel is less expensive than many other types of steel, such as stainless steel or alloy steel, making it a popular choice for manufacturing processes that require large quantities of material.

However, carbon steel does have some limitations. It is susceptible to rust and corrosion, particularly in humid or marine environments. Carbon steel is also less resistant to abrasion and wear than other types of steel, such as alloy steel or tool steel.

Despite these limitations, carbon steel remains an essential material in the manufacturing industry. Its strength, durability, and affordability make it a popular choice for a wide range of applications, from construction materials to industrial machinery. With the ability to be alloyed and heat-treated, carbon steel can be tailored to meet the specific needs of various industries, making it a versatile material that is likely to continue to be in demand for many years to come.





STAINLESS STEELS

Stainless steel is a popular metal alloy with a range of uses due to its high strength, durability, and resistance to corrosion. It is a type of steel alloy that contains a minimum of 10.5% chromium by mass, which forms a thin layer of oxide on the surface of the metal, known as a passive layer. This passive layer protects the metal from further corrosion, making it an excellent choice for applications where it is exposed to corrosive environments.

There are different types of stainless steel, classified based on their microstructure and composition. The most common types of stainless steel are austenitic, ferritic, and martensitic.

Austenitic stainless steel is the most widely used type of stainless steel, known for its excellent corrosion resistance, ductility, and strength. It contains high levels of nickel, chromium, and molybdenum, which makes it highly resistant to corrosion in both acidic and alkaline environments. Austenitic stainless steel is also non-magnetic, making it an ideal choice for applications where magnetic interference must be minimised.

Ferritic stainless steel is characterised by its high resistance to corrosion, particularly in acidic environments. It contains lower levels of nickel and chromium than austenitic stainless steel and is magnetic. Ferritic stainless steel is commonly used in automotive and architectural applications.

Martensitic stainless steel is a high-strength stainless steel that is heat treatable, making it an excellent choice for applications that require high strength and hardness. It contains high levels of carbon and lower levels of nickel than austenitic stainless steel, making it less resistant to corrosion. Martensitic stainless steel is commonly used in applications such as turbine blades, and valves.

Stainless steel is a versatile material used in a range of industries, including food and beverage, aerospace, automotive, and medical equipment. Its excellent resistance to corrosion, strength, and durability make it a popular choice for applications where performance and aesthetics are both important. It is important to understand the different types of stainless steel and their properties to select the appropriate type for a specific application and to use the correct welding techniques to produce high-quality welds.

ALUMINIUM

Aluminium is a lightweight, strong and corrosion-resistant metal that is widely used in a range of industries, including aerospace, automotive, construction, and consumer products. It is the most abundant metal in the earth's crust and is extracted from bauxite ore.

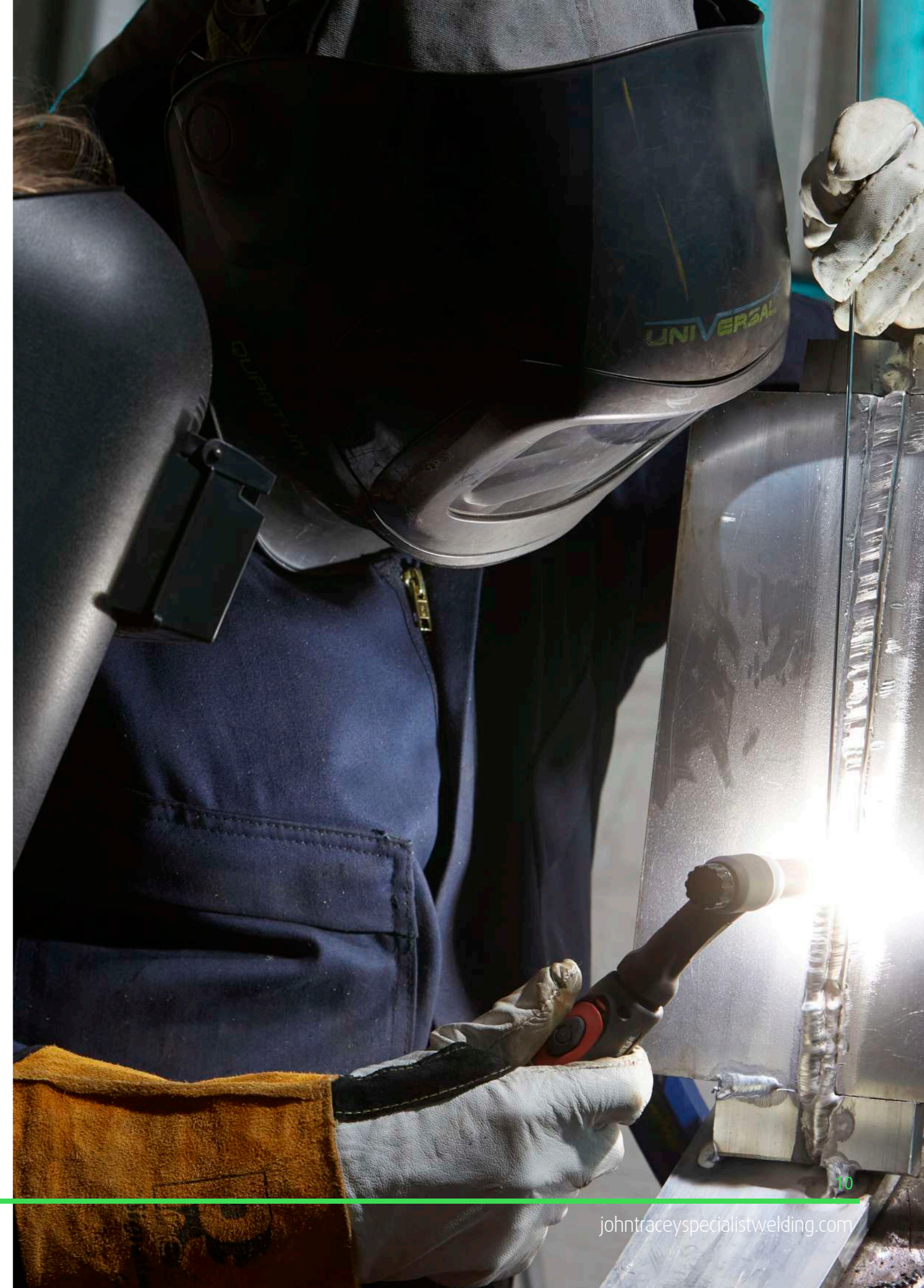
One of the key advantages of aluminium is its low density, which makes it lighter than other metals like steel. This makes it ideal for applications where weight is a concern, such as in the aerospace industry. Despite its light weight, aluminium has high strength and stiffness, making it an excellent choice for structural applications.

Aluminium also has excellent corrosion resistance due to the formation of a thin, protective oxide layer on its surface. This oxide layer prevents further oxidation and corrosion, making it an ideal choice for applications where it is exposed to harsh environments, such as marine and industrial settings.

There are different types of aluminium alloys, each with unique properties and applications. The most commonly used aluminium alloys are 1000 series, 3000 series, 5000 series, and 6000 series. Each series has specific properties, such as corrosion resistance, weldability, and strength.

Aluminium is commonly used in welding due to its light weight, strength, and corrosion resistance. However, welding aluminium can be challenging due to its low melting point, high thermal conductivity, and the presence of oxide layers on its surface. To produce high-quality welds, it is important to use the correct welding techniques, such as TIG (tungsten inert gas) welding or MIG (metal inert gas) welding, and to take appropriate precautions to prevent contamination of the weld.

Aluminium is a versatile metal with a range of properties that make it an ideal choice for various applications. Its lightweight, strength, and corrosion resistance make it an essential component in many industries. Understanding the different types of aluminium alloys and their properties is crucial in selecting the appropriate material for a specific application, and using the correct welding techniques is essential in producing high-quality welds.



Weldability can be defined as:

“The capacity of a metal to be fusion welded in such a manner that the potential properties of the parent metal may be fully exploited”

Weldability refers to the ease with which a metal can be welded without causing defects in the weld or the base metal. Weldability is affected by several factors, including the chemical composition of the metal, its microstructure, and the welding process used.

Essentially weldability refers to the:

- Ability to produce metallurgically sound welded joints. The parent metals and weld metal should combine, without the production of unwanted detrimental constituents of phases.
- The ability to obtain a good match in mechanical properties between the welded metal, heat affected zone and parent metal.
- The ability to produce welded joints that will be capable of meeting subsequent service conditions. For example, while the first two requirements may be adequately met, special requirements may introduce factors such as corrosion resistance or extreme temperatures.

Carbon steel is generally considered to have excellent weldability. This is because it is a relatively soft material and is easily melted and fused. Carbon steel can be welded using a range of welding processes, including MIG (metal inert gas) welding, TIG (tungsten inert gas) welding, and stick welding.

Stainless steel has fair to good weldability, depending on the type of stainless steel being welded. Austenitic stainless steel, which is the most common type of stainless steel, has good weldability due to its high ductility and low carbon content. However, other types of stainless steel, such as martensitic stainless steel, can be more difficult to weld due to their high carbon content and low ductility. Welding stainless steel requires special precautions, such as using low heat input and avoiding contamination of the weld.

Aluminium has fair to good weldability, depending on the type of aluminium alloy being welded. Pure aluminium is relatively easy to weld, but aluminium alloys with high levels of alloying elements, such as copper or magnesium, can be more difficult to weld. Aluminium has a high thermal conductivity, which means that it requires a high heat input to melt and fuse properly. Welding aluminium also requires special precautions, such as using a high-purity shielding gas and cleaning the base metal thoroughly to remove any oxide layers.

In general, the weldability of a metal depends on several factors, including its chemical composition, microstructure, and the welding process used. Understanding these factors is crucial in selecting the appropriate welding technique and ensuring high-quality welds.



FACTORS AFFECTING WELDABILITY



There are many factors affecting weldability that need to be considered including:

Chemical Composition

- The chemical composition of a metal can greatly affect its weldability. Elements such as sulfur and phosphorus can cause cracking in the weld, while elements such as carbon can affect the hardness and strength of the welded joint. Prior condition of plate metal (which takes into account surface condition, chemical composition and mechanical properties)

Microstructure

- The microstructure of a metal, including its grain size and distribution, can also affect its weldability. Metals with fine, uniform grains are generally easier to weld than metals with large, uneven grains

Heat Input

- The amount of heat applied during the welding process can also affect the weldability of a metal. Too little heat can result in incomplete fusion, while too much heat can cause distortion or cracking

Welding Process

- The welding process used can greatly affect the weldability of a metal. Different welding techniques, such as TIG welding, MIG welding, and stick welding, have different heat inputs and require different levels of skill and experience. Also, the weld procedure requirements will have an impact

Surface Preparation

- Proper surface preparation is critical to ensuring good weldability. The surface of the base metal should be clean and free from any contaminants, such as oil, grease, or rust

Welding Environment

- The environment in which welding takes place can also affect weldability. For example, welding in a humid environment can lead to hydrogen embrittlement, while welding in a dirty or contaminated environment can result in weld defects



To include the previous factors in a single test is difficult, therefore the following have been designed...

Mechanical Tests

- These are used to evaluate the mechanical properties of welded joints. Static tests such as tensile, shear, and bending tests are used to measure the strength and stiffness of welded joints. Tensile testing involves applying a tensile force to a welded test specimen until it breaks, and measuring the maximum force that the joint can withstand. Shear testing involves applying a force parallel to the welded joint, while bending testing involves applying a force perpendicular to the joint. Bend testing involves bending a welded test specimen to a specific angle and examining the weld for any cracking or defects. This test can help to evaluate the ductility of the welded joint

Dynamic Tests

- Such as impact and fatigue testing are used to measure the toughness and durability of welded joints. Impact testing involves striking a welded test specimen with a hammer or other impact tool and measuring the amount of energy absorbed by the joint. Fatigue testing involves subjecting a welded joint to cyclic loading and measuring the number of cycles required to cause failure. Hardness testing is another mechanical test that is commonly used to evaluate the hardness of the welded joint

Metallurgical Tests

- These are used to evaluate the microstructure and macrostructure of welded joints. The examination of macro and micro-sections of welded joints can reveal defects such as porosity, cracking, and incomplete penetration. The fracture appearance of mechanically tested joints can also provide valuable information about the quality of the welded joint. For example, Charpy V-notch testing involves striking a welded test specimen with a heavy hammer and measuring the energy required to fracture the sample. This test measures the impact toughness of the welded joint and can help to identify any brittle behaviour or defects in the weld. Hardness testing involves measuring the hardness of the welded joint using a hardness tester. This test can help to identify any changes in the metal's hardness due to the welding process

Technical Tests

- Are used to investigate the cracking tendency of welds and comprise restrained cracking and ductility tests. Crack susceptibility testing involves subjecting a welded test specimen to a stress that is known to cause cracking and measuring the crack length and severity. Restraint cracking tests are used to evaluate the susceptibility of welded joints to cracking under different types of restraint. Ductility testing involves measuring the degree of plastic deformation that a welded joint can undergo before failure

Weld defects are imperfections that occur during the welding process and can weaken or compromise the integrity of the welded joint. Weld defects vary in shape and size and in significance dependant on the position in the weld or the heat affected zone and the thickness. Weld defects include:

Porosity

Porosity is the presence of small voids or gas pockets in the welded joint. These voids can weaken the joint and make it more susceptible to cracking. Porosity is one of the most common defects found in welding. Porosity can occur due to a variety of reasons, such as improper shielding gas flow, improper electrode or filler wire selection, inadequate welding techniques, or dirty base material.

Porosity defects in welding can significantly weaken the welded joint and reduce its load-bearing capacity. The voids or gas pockets can act as stress concentrators, leading to premature failure of the joint. Additionally, porosity can also cause leakage or contamination of the welded joint, which can be particularly problematic in applications where the joint is exposed to corrosive or hazardous substances.

To prevent porosity defects in welding, it is important to ensure proper shielding gas flow and composition, use the correct welding technique and parameters, clean the base material properly, and select the appropriate filler material. Additionally, welders should inspect the weld bead for porosity during and after welding and take corrective action if necessary. By taking these precautions, welders can prevent porosity defects and ensure the quality and reliability of the welded joint.

Incomplete Penetration

Incomplete penetration is a common welding defect that occurs when the weld metal fails to penetrate through the full thickness of the base metal. This results in a gap or void in the joint, which can weaken the joint and reduce its load-bearing capacity. Incomplete penetration can occur due to a variety of factors, such as incorrect welding technique, insufficient heat input, or using the wrong welding parameters.

In some cases, incomplete penetration can be difficult to detect by visual inspection alone, and it may require the use of non-destructive testing methods, such as X-ray or ultrasonic testing, to identify the defect. If left undetected, incomplete penetration can result in premature failure of the welded joint, which can be particularly problematic in applications where the joint is exposed to high stresses or harsh environments.

To prevent incomplete penetration defects in welding, it is important to use the correct welding technique and parameters, ensure adequate heat input, and properly prepare the base material. Additionally, welders should inspect the weld bead during and after welding to ensure that the weld metal has fully penetrated the base material. By taking these precautions, welders can prevent incomplete penetration defects and ensure the quality and reliability of the welded joint.



Cracking

Cracking is a serious welding defect that can occur due to a variety of reasons, such as high welding stresses, improper welding technique, or inadequate preparation of the base material. Cracks can be classified into several types, such as longitudinal cracks, transverse cracks, and crater cracks, depending on their orientation and location in the weld joint.

Cracking can significantly weaken the welded joint and reduce its load-bearing capacity. Additionally, cracks can propagate rapidly and lead to catastrophic failure of the joint, which can be particularly problematic in applications where the joint is exposed to high stresses or dynamic loading.

To prevent cracking defects in welding, it is important to use the correct welding technique and parameters, control welding stresses, and properly prepare the base material. Additionally, welders should inspect the weld bead during and after welding to identify any signs of cracking and take corrective action if necessary. Non-destructive testing methods, such as X-ray or ultrasonic testing, can also be used to detect cracks in the welded joint. By taking these precautions, welders can prevent cracking defects and ensure the quality and reliability of the welded joint.

WELD

DEFECTS

Lack of Fusion

Lack of fusion occurs when the weld metal fails to fuse properly with the base material. This results in a gap or void in the joint, which can weaken the joint and reduce its load-bearing capacity. Lack of fusion can occur due to a variety of factors, such as incorrect welding technique, insufficient heat input, or using the wrong welding parameters.

Lack of fusion can be particularly problematic in applications where the welded joint is exposed to high stresses or dynamic loading. In some cases, lack of fusion can be difficult to detect by visual inspection alone, and it may require the use of non-destructive testing methods, such as X-ray or ultrasonic testing, to identify the defect.

To prevent lack of fusion defects in welding, it is important to use the correct welding technique and parameters, ensure adequate heat input, and properly prepare the base material. Additionally, welders should inspect the weld bead during and after welding to ensure that the weld metal has properly fused with the base material. By taking these precautions, welders can prevent lack of fusion defects and ensure the quality and reliability of the welded joint.

Undercut

Undercut occurs when the base material is melted excessively during the welding process, resulting in a groove or depression along the edge of the weld joint. This can weaken the joint and reduce its load-bearing capacity, as well as make it more prone to cracking and corrosion.

Undercut can occur due to a variety of factors, such as incorrect welding technique, using the wrong welding parameters, or inadequate preparation of the base material. Additionally, undercut can be difficult to detect by visual inspection alone, and it may require the use of non-destructive testing methods, such as X-ray or ultrasonic testing, to identify the defect.

To prevent undercut defects in welding, it is important to use the correct welding technique and parameters, ensure adequate heat input, and properly prepare the base material. Additionally, welders should inspect the weld bead during and after welding to ensure that the base material has not been excessively melted. By taking these precautions, welders can prevent undercut defects and ensure the quality and reliability of the welded joint.

Weld defects can be caused by a variety of factors, including improper welding technique, incorrect welding parameters, and poor welding conditions. Weld defects can be detected and evaluated using various non-destructive testing techniques, such as radiography, ultrasonic testing, and magnetic particle testing.



WELD

DEFECTS

NON-DESTRUCTIVE TESTING

Non-Destructive Testing (NDT) is a technique used in various industries to inspect and evaluate the integrity of materials or components without damaging them. This allows for identification of defects, discontinuities or other anomalies that could affect the structural integrity or performance of the material or component. NDT plays a critical role in ensuring the safety and reliability of structures and equipment in industries such as aerospace, automotive, construction, and manufacturing.

NDT techniques can be broadly classified into four categories: Visual, Radiographic, Ultrasonic and Magnetic Particle Inspection. Each category comprises various techniques and methods, such as Magnetic Particle Inspection (MPI), Dye Penetrant Inspection (DPI), and Ultrasonic Testing (UT), among others.

Magnetic Particle Inspection (MPI)

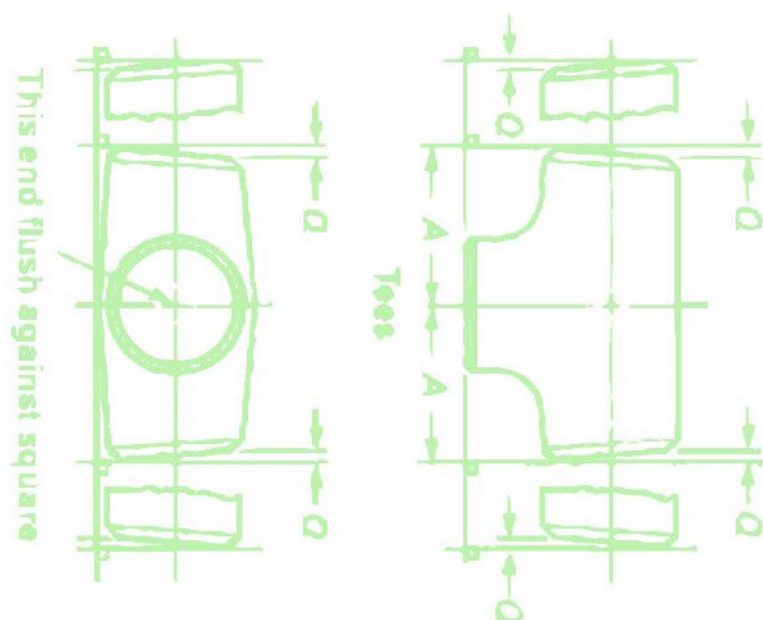
Magnetic particle inspection (MPI) is a non-destructive testing method used to detect surface and slightly subsurface discontinuities in ferromagnetic materials. This technique is based on the principles of magnetism and electromagnetic induction.

In MPI, a magnetic field is created in the component being inspected. The component is then coated with a ferromagnetic particle, usually iron oxide or iron oxide-coated particles, suspended in a liquid. If there is a surface-breaking or slightly subsurface discontinuity, such as a crack or a void, the magnetic field lines will be distorted, and the particles will be attracted to the defect and form a visible indication, known as an "indication" or "discontinuity."

MPI can be performed using two methods: wet and dry. In the wet method, the particles are suspended in a liquid and sprayed onto the component, while in the dry method, the particles are dry and applied through a magnetic field. The wet method is more commonly used as it provides better particle mobility and adherence to the surface.

MPI is a highly effective method for detecting surface and subsurface discontinuities in ferromagnetic materials. However, it is limited to ferromagnetic materials only, and the detection capabilities are limited to surface or near-surface flaws.

MPI is commonly used in the inspection of welds, castings, and forgings in industries such as oil and gas, aerospace, automotive, and construction. It is also used in the inspection of rail tracks, bridges, and pipelines.





Dye Penetrant Inspection (DPI)

Dye penetrant inspection (DPI), also known as liquid penetrant inspection (LPI), is a non-destructive testing method used to detect surface-breaking defects in non-porous materials such as metals, ceramics, and plastics. This technique is based on the principle of capillary action, whereby a low-viscosity liquid penetrates into the surface-breaking discontinuities.

In DPI, a dye penetrant solution is applied to the surface of the material being inspected. The solution penetrates into any surface-breaking defects such as cracks, porosity, or laps, through capillary action. After a sufficient penetration time, the excess penetrant is removed, and a developer is applied. The developer draws the penetrant to the surface and forms a visible indication of the defect.

DPI can be performed using three methods: the visible dye method, the fluorescent dye method, and the water-washable method. In the visible dye method, the penetrant contains a dye that is visible to the naked eye. In the fluorescent dye method, the penetrant contains a fluorescent dye that requires an ultraviolet light to be visible. In the water-washable method, a water-soluble penetrant is used, and the excess penetrant is washed off with water before the developer is applied.

DPI is a highly effective method for detecting surface-breaking defects in non-porous materials. However, it is limited to detecting only surface-breaking defects and is not effective for detecting subsurface or internal defects.

DPI is commonly used in the inspection of welds, castings, forgings, and machined components in industries such as aerospace, automotive, and manufacturing. It is also used in the inspection of piping systems, pressure vessels, and storage tanks.



Ultrasonic Testing (UT)

Ultrasonic testing (UT) is a non-destructive testing method that uses high-frequency sound waves to detect defects and measure material thickness in metals, plastics, and composites. UT works on the principle that sound waves can travel through materials and reflect back when they encounter an interface between different materials or a defect within a material.

In UT, a transducer is used to send high-frequency sound waves into the material being inspected. When the sound waves encounter an interface or a defect within the material, part of the sound waves are reflected back to the transducer. The transducer detects these reflected waves and converts them into an electrical signal, which is analyzed by a computer or an operator.

UT can detect a variety of defects, including cracks, inclusions, voids, and porosity, as well as measure the thickness of materials. UT can be performed using two methods: contact and immersion. In contact UT, the transducer is in direct contact with the surface of the material being inspected. In immersion UT, the material is immersed in a liquid or water tank, and the transducer is placed in the liquid.

UT is a highly sensitive and accurate method for detecting defects and measuring material thickness. However, it requires a skilled operator to interpret the results accurately, and the material being inspected must be accessible to the transducer.

UT is commonly used in the inspection of welds, castings, forgings, and composites in industries such as aerospace, automotive, and manufacturing. It is also used in the inspection of piping systems, pressure vessels, and storage tanks.