= current (A) , and S =
welding speed (mm / min) . The efficiency is dependent on the welding process used , with shielded metal arc welding having a value of 0 @.@ 75 , gas metal arc welding and submerged arc welding , 0 @.@ 9 , and gas tungsten arc welding , 0 @.@ 8 .

= = = Lifetime extension with aftertreatment methods = = =

The durability and life of dynamically loaded , welded steel structures is determined in many cases by the welds , particular the weld transitions . Through selective treatment of the transitions by grinding (abrasive cutting) , shot peening , High Frequency Impact Treatment , etc. the durability of many designs increase significantly .

= = Metallurgy = =

Most solids used are engineering materials consisting of crystalline solids in which the atoms or ions are arranged in a repetitive geometric pattern which is known as a lattice structure . The only exception is material that is made from glass which is a combination of a supercooled liquid and polymers which are aggregates of large organic molecules .
Crystalline solids cohesion is obtained by a metallic or chemical bond which is formed between the constituent atoms . Chemical bonds can be grouped into two types consisting of ionic and covalent . To form an ionic bond , either a valence or bonding electron separates from one atom and becomes attached to another atom to form oppositely charged ions . The bonding in the static position is when the ions occupy an equilibrium position where the resulting force between them is zero . When the ions are exerted in tension force , the inter @-@ ionic spacing increases creating an electrostatic attractive force , while a repulsing force under compressive force between the atomic nuclei is dominant .
Covalent bonding takes place when one of the constituent atoms loses one or more electrons , with the other atom gaining the electrons , resulting in an electron cloud that is shared by the molecule as a whole . In both ionic and covalent bonding the location of the ions and electrons are constrained relative to each other , thereby resulting in the bond being characteristically brittle .
Metallic bonding can be classified as a type of covalent bonding for which the constituent atoms of the same type and do not combine with one another to form a chemical bond . Atoms will lose an electron (s) forming an array of positive ions . These electrons are shared by the lattice which makes the electron cluster mobile , as the electrons are free to move as well as the ions . For this , it gives metals their relatively high thermal and electrical conductivity as well as being characteristically ductile .
Three of the most commonly used crystal lattice structures in metals are the body @-@ centred cubic , face @-@ centred cubic and close @-@ packed hexagonal . Ferritic steel has a body @-@ centred cubic structure and austenitic steel , non @-@ ferrous metals like aluminum , copper and nickel have the face @-@ centred cubic structure .
Ductility is an important factor in ensuring the integrity of structures by enabling them to sustain local stress concentrations without fracture . In addition , structures are required to be of an acceptable strength , which is related to a material 's yield strength . In general , as the yield strength of a material increases , there is a corresponding reduction in fracture toughness .
A reduction in fracture toughness may also be attributed to the embrittlement effect of impurities , or for body @-@ centred cubic metals , from a reduction in temperature . Metals and in particular steels have a transitional temperature range where above this range the metal has acceptable notch @-@ ductility while below this range the material becomes brittle . Within the range , the materials behavior is unpredictable . The reduction in fracture toughness is accompanied by a change in the fracture appearance . When above the transition , the fracture is primarily due to micro @-@ void coalescence , which results in the fracture appearing fibrous . When the temperatures falls the fracture will show signs of cleavage facets . These two appearances are visible by the naked eye . Brittle fracture in steel plates may appear as chevron markings under the microscope . These arrow

@-@ like ridges on the crack surface point towards the origin of the fracture .
Fracture toughness is measured using a notched and pre @-@ cracked rectangular specimen , of which the dimensions are specified in standards , for example ASTM E23 . There are other means of estimating or measuring fracture toughness by the following : The Charpy impact test per ASTM A370 ; The crack @-@ tip opening displacement (CTOD) test per BS 7448 @-@ 1 ; The J integral test per ASTM E1820 ; The Pellini drop @-@ weight test per ASTM E208 .

= = Unusual conditions = =

While many welding applications are done in controlled environments such as factories and repair shops , some welding processes are commonly used in a wide variety of conditions , such as open air , underwater , and vacuums (such as space) . In open @-@ air applications , such as construction and outdoors repair , shielded metal arc welding is the most common process . Processes that employ inert gases to protect the weld cannot be readily used in such situations , because unpredictable atmospheric movements can result in a faulty weld . Shielded metal arc welding is also often used in underwater welding in the construction and repair of ships , offshore platforms , and pipelines , but others , such as flux cored arc welding and gas tungsten arc welding , are also common . Welding in space is also possible ? it was first attempted in 1969 by Russian cosmonauts , when they performed experiments to test shielded metal arc welding , plasma arc welding , and electron beam welding in a depressurized environment . Further testing of these methods was done in the following decades , and today researchers continue to develop methods for using other welding processes in space , such as laser beam welding , resistance welding , and friction welding . Advances in these areas may be useful for future endeavours similar to the construction of the International Space Station , which could rely on welding for joining in space the parts that were manufactured on Earth .

= = Safety issues = =

Welding can be dangerous and unhealthy if the proper precautions are not taken . However , using new technology and proper protection greatly reduces risks of injury and death associated with welding . Since many common welding procedures involve an open electric arc or flame , the risk of burns and fire is significant ; this is why it is classified as a hot work process . To prevent injury , welders wear personal protective equipment in the form of heavy leather gloves and protective long @-@ sleeve jackets to avoid exposure to extreme heat and flames . Additionally , the brightness of the weld area leads to a condition called arc eye or flash burns in which ultraviolet light causes inflammation of the cornea and can burn the retinas of the eyes . Goggles and welding helmets with dark UV @-@ filtering face plates are worn to prevent this exposure . Since the 2000s , some helmets have included a face plate which instantly darkens upon exposure to the intense UV light . To protect bystanders , the welding area is often surrounded with translucent welding curtains . These curtains , made of a polyvinyl chloride plastic film , shield people outside the welding area from the UV light of the electric arc , but can not replace the filter glass used in helmets .
Welders are often exposed to dangerous gases and particulate matter . Processes like flux @-@ cored arc welding and shielded metal arc welding produce smoke containing particles of various types of oxides . The size of the particles in question tends to influence the toxicity of the fumes , with smaller particles presenting a greater danger . This is because smaller particles have the ability to cross the blood brain barrier . Fumes and gases , such as carbon dioxide , ozone , and fumes containing heavy metals , can be dangerous to welders lacking proper ventilation and training . Exposure to manganese welding fumes , for example , even at low levels (< 0 @.@ 2 mg / m3) , may lead to neurological problems or to damage to the lungs , liver , kidneys , or central nervous system . Nano particles can become trapped in the alveolar macrophages of the lungs and induce pulmonary fibrosis . The use of compressed gases and flames in many welding processes poses an explosion and fire risk . Some common precautions include limiting the amount of oxygen in the air , and keeping combustible materials away from the workplace .

Costs and trends

As an industrial process , the cost of welding plays a crucial role in manufacturing decisions . Many different variables affect the total cost , including equipment cost , labor cost , material cost , and energy cost . Depending on the process , equipment cost can vary , from inexpensive for methods like shielded metal arc welding and oxyfuel welding , to extremely expensive for methods like laser beam welding and electron beam welding . Because of their high cost , they are only used in high production operations . Similarly , because automation and robots increase equipment costs , they are only implemented when high production is necessary . Labor cost depends on the deposition rate (the rate of welding) , the hourly wage , and the total operation time , including time spent fitting , welding , and handling the part . The cost of materials includes the cost of the base and filler material , and the cost of shielding gases . Finally , energy cost depends on arc time and welding power demand .

For manual welding methods , labor costs generally make up the vast majority of the total cost . As a result , many cost @-@ saving measures are focused on minimizing operation time . To do this , welding procedures with high deposition rates can be selected , and weld parameters can be fine @-@ tuned to increase welding speed . Mechanization and automation are often implemented to reduce labor costs , but this frequently increases the cost of equipment and creates additional setup time . Material costs tend to increase when special properties are necessary , and energy costs normally do not amount to more than several percent of the total welding cost .

In recent years , in order to minimize labor costs in high production manufacturing , industrial welding has become increasingly more automated , most notably with the use of robots in resistance spot welding (especially in the automotive industry) and in arc welding . In robot welding , mechanized devices both hold the material and perform the weld and at first , spot welding was its most common application , but robotic arc welding increases in popularity as technology advances . Other key areas of research and development include the welding of dissimilar materials (such as steel and aluminum , for example) and new welding processes , such as friction stir , magnetic pulse , conductive heat seam , and laser @-@ hybrid welding . Furthermore , progress is desired in making more specialized methods like laser beam welding practical for more applications , such as in the aerospace and automotive industries . Researchers also hope to better understand the often unpredictable properties of welds , especially microstructure , residual stresses , and a weld 's tendency to crack or deform .

The trend of accelerating the speed at which welds are performed in the steel erection industry comes at a risk to the integrity of the connection . Without proper fusion to the base materials provided by sufficient arc time on the weld , a project inspector cannot ensure the effective diameter of the puddle weld therefore he or she cannot guarantee the published load capacities unless they witness the actual installation . This method of puddle welding is common in the United States and Canada for attaching steel sheets to bar joist and structural steel members . Regional agencies are responsible for ensuring the proper installation of puddle welding on steel construction sites . Currently there is no standard or weld procedure which can ensure the published holding capacity of any unwitnessed connection , but this is under review by the American Welding Society .

Glass and plastic welding

Glasses and certain types of plastics are commonly welded materials . Unlike metals , which have a specific melting point , glasses and plastics have a melting range , called the glass transition . When heating the solid material into this range , it will generally become softer and more pliable . When it crosses through the glass transition , it will become a very thick , sluggish , viscous liquid . Typically , this viscous liquid will have very little surface tension , becoming a sticky , honey @-@ like consistency , so welding can usually take place by simply pressing two melted surfaces together . The two liquids will generally mix and join at first contact . Upon cooling through the glass transition , the welded piece will solidify as one solid piece of amorphous material .

= = = Glass welding = = =

Glass welding is a common practice during glassblowing . It is used very often in the construction of lighting , neon signs , flashtubes , scientific equipment , and the manufacture of dishes and other glassware . It is also used during glass casting for joining the halves of glass molds , making items such as bottles and jars . Welding glass is accomplished by heating the glass through the glass transition , turning it into a thick , formable , liquid mass . Heating is usually done with a gas or oxy @-@ gas torch , or a furnace , because the temperatures for melting glass are often quite high . This temperature may vary , depending on the type of glass . For example , lead glass becomes a weldable liquid at around 1 @,@ 600 ° F (870 ° C) , and can be welded with a simple propane torch . On the other hand , quartz glass (fused silica) must be heated to over 3 @,@ 000 ° F (1 @,@ 650 ° C) , but quickly loses its viscosity and formability if overheated , so an oxyhydrogen torch must be used . Sometimes a tube may be attached to the glass , allowing it to be blown into various shapes , such as bulbs , bottles , or tubes . When two pieces of liquid glass are pressed together , they will usually weld very readily . Welding a handle onto a pitcher can usually be done with relative ease . However , when welding a tube to another tube , a combination of blowing and suction , and pressing and pulling is used to ensure a good seal , to shape the glass , and to keep the surface tension from closing the tube in on itself . Sometimes a filler rod may be used , but usually not .

Because glass is very brittle in its solid state , it is often prone to cracking upon heating and cooling , especially if the heating and cooling are uneven . This is because the brittleness of glass does not allow for uneven thermal expansion . Glass that has been welded will usually need to be cooled very slowly and evenly through the glass transition , in a process called annealing , to relieve any internal stresses created by a temperature gradient .

There are many types of glass , and it is most common to weld using the same types . Different glasses often have different rates of thermal expansion , which can cause them to crack upon cooling when they contract differently . For instance , quartz has very low thermal expansion , while soda @-@ lime glass has very high thermal expansion . When welding different glasses to each other , it is usually important to closely match their coefficients of thermal expansion , to ensure that cracking does not occur . Also , some glasses will simply not mix with others , so welding between certain types may not be possible .

Glass can also be welded to metals and ceramics , although with metals the process is usually more adhesion to the surface of the metal rather than a commingling of the two materials . However , certain glasses will typically bond only to certain metals . For example , lead glass bonds readily to copper or molybdenum , but not to aluminum . Tungsten electrodes are often used in lighting but will not bond to quartz glass , so the tungsten is often wetted with molten borosilicate glass , which bonds to both tungsten and quartz . However , care must be taken to ensure that all materials have similar coefficients of thermal expansion to prevent cracking both when the object cools and when it is heated again . Special alloys are often used for this purpose , ensuring that the coefficients of expansion match , and sometimes thin , metallic coatings may be applied to a metal to create a good bond with the glass .

= = = Plastic welding = = =

Plastics are generally divided into two categories , which are " thermosets " and " thermoplastics . " A thermoset is a plastic in which a chemical reaction sets the molecular bonds after first forming the plastic , and then the bonds cannot be broken again without degrading the plastic . Thermosets cannot be melted , therefore , once a thermoset has set it is impossible to weld it . Examples of thermosets include epoxies , silicone , vulcanized rubber , polyester , and polyurethane .

Thermoplastics , by contrast , form long molecular chains , which are often coiled or intertwined , forming an amorphous structure without any long @-@ range , crystalline order . Some thermoplastics may be fully amorphous , while others have a partially crystalline / partially amorphous structure . Both amorphous and semicrystalline thermoplastics have a glass transition , above which welding can occur , but semicrystallines also have a specific melting point which is above the glass transition . Above this melting point , the viscous liquid will become a free @-@ flowing liquid (see rheological weldability for thermoplastics) . Examples of thermoplastics include polyethylene , polypropylene , polystyrene , polyvinylchloride (PVC) , and fluoroplastics like Teflon and Spectralon .

Welding thermoplastic is very similar to welding glass . The plastic first must be cleaned and then heated through the glass transition , turning the weld @-@ interface into a thick , viscous liquid . Two heated interfaces can then be pressed together , allowing the molecules to mix through intermolecular diffusion , joining them as one . Then the plastic is cooled through the glass transition , allowing the weld to solidify . A filler rod may often be used for certain types of joints . The main differences between welding glass and plastic are the types of heating methods , the much lower melting temperatures , and the fact that plastics will burn if overheated . Many different methods have been devised for heating plastic to a weldable temperature without burning it . Ovens or electric heating tools can be used to melt the plastic . Ultrasonic , laser , or friction heating are other methods . Resistive metals may be implanted in the plastic , which respond to induction heating . Some plastics will begin to burn at temperatures lower than their glass transition , so welding can be performed by blowing a heated , inert gas onto the plastic , melting it while , at the same time , shielding it from oxygen .

Many thermoplastics can also be welded using chemical solvents . When placed in contact with the plastic , the solvent will begin to soften it , bringing the surface into a thick , liquid solution . When two melted surfaces are pressed together , the molecules in the solution mix , joining them as one . Because the solvent can permeate the plastic , the solvent evaporates out through the surface of the plastic , causing the weld to drop out of solution and solidify . A common use for solvent welding is for joining PVC or ABS (acrylonitrile butadiene styrene) pipes during plumbing , or for welding styrene and polystyrene plastics in the construction of models . Solvent welding is especially effective on plastics like PVC which burn at or below their glass transition , but may be ineffective on plastics like Teflon or polyethylene that are resistant to chemical decomposition .