I'm not a robot

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The course covers 5 units: 1) gas and arc welding processes, 2) resistance welding processes, 3) solSaveSave Welding Technology Syllabus For Later100%100% found this document useful, undefined Just $150 per student, plus shipping costs, with a minimum of 10 studentsmaking quality training accessible to institutions of all sizes. A complete spectrum of welding techniques applicable in academic and professional settings. FOWC and all AWS training programs are developed within the U.S. for the rigors and standards of the U.S. marketplace. Prepares students to earn welding credentials that open doors to job opportunities. Meets AWS SENSE standards for foundational welding skills and prepares learners for AWS welding certification. Adaptable to in-person, hybrid, and virtual learning environments. Covers core welding skills from theory to hands-on practice. Includes textbooks, e-learning modules, instructional videos, and more to support diverse learning styles. Fabrication process for joining materials"Welded" redirects here. For the play, see Welded (play).Overhead stick weldingWelding is a fabrication process that joins materials, usually metals or thermoplastics, primarily by using high temperature to melt the parts together and allow them to cool, causing fusion. Common alternative methods include solvent welding (of thermoplastics) using chemicals to melt materials being bonded without heat, and solid-state welding processes which bond without melting, such as pressure, cold welding, and diffusion bonding.Metal welding is distinct from lower temperature bonding techniques such as brazing and soldering, which do not melt the base metal (parent metal) and instead require flowing a filler metal to solidify their bonds.In addition to melting the base metal in welding, a filler material is typically added to the joint to form a pool of molten material (the weld pool) that cools to form a joint that can be stronger than the base material. Welding also requires a form of shield to protect the filler metals or melted metals from being contaminated or oxidized.Many different energy sources can be used for welding, including a gas flame (chemical), an electric arc (electrical), a laser, an electron beam, friction, and ultrasound. While often an industrial process, welding may be performed in many different environments, including in open air, under water, and in outer space. Welding is a hazardous undertaking and precautions are required to avoid burns, electric shock, vision damage, inhalation of poisonous gases and fumes, and exposure to intense ultraviolet radiation.Until the end of the 19th century, the only welding process was forge welding, which blacksmiths had used for millennia to join iron and steel by heating and hammering. Arc welding and oxy-fuel welding were among the first processes to develop late in the century, and electric resistance welding followed soon after. Welding technology advanced quickly during the early 20th century, as world wars drove the demand for reliable and inexpensive joining methods. Following the wars, several modern welding techniques were developed, including manual methods like shielded metal arc welding, now one of the most popular welding methods, as well as semi-automatic and automatic processes such as gas metal arc welding, submerged arc welding, flux-cored arc welding and electroslag welding. Developments continued with the invention of laser beam welding, electron beam welding, magnetic pulse welding, and friction stir welding in the latter half of the century. Today, as the science continues to advance, robot welding is commonplace in industrial settings, and researchers continue to develop new welding methods and gain greater understanding of weld quality.[1]The term weld is derived from the Middle English verb well (wll; plural/present tense: wlle) or welling (wllen), meaning 'to heat' (to the maximum temperature possible); 'to bring to a boil'. The modern word was probably derived from the past-tense participle welled (wllende), with the addition of d for this purpose being common in the Germanic languages of the Angles and Saxons. It was first recorded in English in 1590. A fourteenth century translation of the Christian Bible into English by John Wycliffe translates Isaiah 2:4 as "...thei shul bete togidere their swerdes into shares..." (they shall beat together their swords into plowshares). In the 1590 version this was changed to "...thei shullen welle togidere her swerdes in-to scharris..." (they shall weld together their swords into plowshares), suggesting this particular use of the word probably became popular in English sometime between these periods.[2]The Old English word for welding iron was samod ('to bring together') or samodwellung ('to bring together hot').[3]The word is related to the Old Swedish word valla, meaning 'to boil', which could refer to joining metals, as in valla jrn (literally 'to boil iron'). Sweden was a large exporter of iron during the Middle Ages, so the word may have entered English from the Swedish iron trade, or may have been imported with the thousands of Viking settlements that arrived in England before and during the Viking Age, as more than half of the most common English words in everyday use are Scandinavian in origin.[4][5]The iron pillar of Delhi, IndiaThe history of joining metals goes back several millennia.[6] Fusion welding processes that join metals by melting them were not widely used in pre-industrial welding. Early welding techniques used pressure to join to the metals, often with heat not sufficient to fully melt the base metals.[7] One notable exception was a technique to join sections of large statues. In Greek and Roman lost-wax casting, the statues were cast as smaller pieces and molten bronze was poured into the joints with temperatures sufficient to create fusion welds.[8]The earliest known welding dates to the Bronze Age. Gold is soft enough to be pressure welded with little to no heat, and archaeologists have found small boxes made by pressure welding overlapping sheets of gold. In the Iron Age, Mediterranean societies developed forge welding.[9] In forge welding, metal is heated to the point that it becomes soft enough for a blacksmith to hammer separate pieces together.[10] Very early notable examples are the iron objects found with Tutankhamun including an iron headrest and dagger.[11][12] The dagger was forged from meteoric iron at temperatures below 950C (1,740F).[13] Typically, wrought iron is forged at around 1,350C (2,460F).[14] The ancient Greek historian Herodotus credits Glaucus of Chios with discovering "iron welding".[15] Glaucus is known for an iron pedestal welded to hold a silver krater at Delphi.[16]Forge welding in 1904[17]The Middle Ages brought advances in forge welding, in which blacksmiths pounded heated metal repeatedly until bonding occurred.[18] In Europe and Africa, forging shifted from open charcoal fires to bloomeries. China developed the blast furnace late in the first millennia.[19] Forge welding was used in the construction of the Iron pillar of Delhi, erected in Delhi, India about 310 AD and weighing 5.4metric tons.[20] In 1540, Vannoccio Biringuccio published De la pirotechnia, which includes descriptions of the forging operation.[18] Renaissance craftsmen were skilled in the process, and the industry continued to grow during the following centuries.[18]In 1800, Sir Humphry Davy discovered the short-pulse electrical arc and presented his results in 1801.[21][22][23] In 1802, Russian scientist Vasily Petrov created the continuous electric arc,[23][24][25] and subsequently published "News of Galvanic-Voltaic Experiments" in 1803, in which he described experiments carried out in 1802. Of great importance in this work was the description of a stable arc discharge and the indication of its possible use for many applications, one being melting metals.[26] In 1808, Davy, who was unaware of Petrov's work, rediscovered the continuous electric arc.[22][23] In 188182 inventors Nikolai Benardos (Russian) and Stanisaw Olszewski (Polish)[27] created the first electric arc welding method known as carbon arc welding using carbon electrodes. The advances in arc welding continued with the invention of metal electrodes in the late 1800s by a Russian, Nikolai Slavyanov (1888), and an American, C. L. Coffin (1890). Around 1900, A. P. Strohmenger released a coated metal electrode in Britain, which gave a more stable arc. In 1905, Russian scientist Vladimir Mitkevich proposed using a three-phase electric arc for welding. Alternating current welding was invented by C. J. Holslag in 1919, but did not become popular for another decade.[28]Resistance welding was also developed during the final decades of the 19th century, with the first patents going to Elihu Thomson in 1885, who produced further advances over the next 15 years. Thermite welding was invented in 1893, and around that time another process, oxyfuel welding, became well established. Acetylene was discovered in 1836 by Edmund Davy, but its use was not practical in welding until about 1900, when a suitable torch was developed.[29] At first, oxyfuel welding was one of the more popular welding methods due to its portability and relatively low cost. As the 20th century progressed, however, it fell out of favor for industrial applications. It was largely replaced with arc welding, as advances in metal coverings (known as flux) were made.[30] Flux covering the electrode primarily shields the base material from impurities, but also stabilizes the arc and can add alloying components to the weld metal.[31]Acetylene welding on cylinder water jacket, US Army 1918World War I caused a major surge in the use of welding, with the various military powers attempting to determine which of the several new welding processes would be best.[32] The British primarily used arc welding, even constructing a ship, the "Fullagar" with an entirely welded hull.[33][34]:142 Arc welding was first applied to aircraft during the war as well, as some German airplane fuselages were constructed using the process.[35]During the middle of the century, many new welding methods were invented, including the introduction of automatic welding in 1920, in which electrode wire was fed continuously.[36] Shielding gas received much attention, as scientists attempted to protect welds from the effects of oxygen and nitrogen in the atmosphere. Porosity and brittleness were the primary problems, and the solutions that developed included the use of hydrogen, argon, and helium as welding atmospheres.[37] Testing methods were introduced for weld integrity. First vibration testing was done using a hammer and stethoscope; later, X-ray tests were developed to see into the weld.[38] During the 1930s, further advances allowed for the welding of reactive metals like aluminum and magnesium.[39] This in conjunction with developments in automatic welding, alternating current, and fluxes fed a major expansion of arc welding during the 1930s.[40] Russian inventor Konstantin Khrenov implemented the first underwater electric arc welding.[41] In 1930, Kyle Taylor was responsible for the release of stud welding, which soon became popular in shipbuilding and construction. Submerged arc welding was invented the same year.[42] During World War II, submerged arc welding was widely used for ship-building because it allowed certain types of welds to be done twenty times faster than earlier techniques.[43]Bridge of MaurzyceImprovements to welding processes opened up new possibilities for construction.[44] Previously, large metal structures had been made from metals joined mechanically with rivets, along with bolts, screws, and belts. These connected but unfused metal structures had inherent weaknesses.[45] The steamboat Sultana killed over a thousand passengers when its riveted boiler failed under pressure.[46] The "unsinkable" Titanic sank due in part to failures in its riveted hull.[47] In 1930, the first all-welded merchant vessel, M/S Carolinian, was launched.[48] The strength of welded steel also allowed for the creation of entirely new types of ships, notably the liquefied natural gas (LNG) tanker. The ASME Boiler and Pressure Vessel Code, created in response to deadly boiler failures was used to develop the spherical tanks that contain LNG during transport.[49] Also noteworthy is the first welded road bridge in the world, the Maurzyce Bridge in Poland (1928).[33] Early skyscrapers and steel truss bridges were built from riveted steel beams.[50][51] Welding allows for stronger and lighter structures and greater range of shapes.[52] The Sydney Opera House's icon shape is built on a stud-welded steel frame.[53]Portable welder being used for Sydney stormwater infrastructure Gas tungsten arc welding, after decades of development, was finally perfected in 1941, and gas metal arc welding followed in 1948, allowing for fast welding of non-ferrous materials but requiring expensive shielding gases. Shielded metal arc welding was developed during the 1950s, using a flux-coated consumable electrode, and it quickly became the most popular metal arc welding process. In 1957, the flux-cored arc welding process debuted, in which the self-shielded wire electrode could be used with automatic equipment, resulting in greatly increased welding speeds, and that same year, plasma arc welding was invented by Robert Gage. Electroslag welding was introduced in 1958, and it was followed by its cousin, electrogas welding, in 1961.[54] In 1953, the Soviet scientist N. F. Kazakov proposed the diffusion bonding method.[55]Other recent developments in welding include the 1958 breakthrough of electron beam welding, making deep and narrow welding possible through the concentrated heat source. Following the invention of the laser in 1960, laser beam welding debuted several decades later, and has proved to be especially useful in high-speed, automated welding. Magnetic pulse welding (MPW) has been industrially used since 1967. Friction stir welding was invented in 1991 by Wayne Thomas at The Welding Institute (TWI, UK) and found high-quality applications all over the world.[56] All of these four new processes continue to be quite expensive due to the high cost of the necessary equipment, and this has limited their applications.[57]Gas metal arc welding (GMAW) filmed through a shaded lens[58]Welding joins two pieces of metal using heat, pressure, or both. The most common modern welding methods use heat sufficient to melt the base metals to be joined and the filler metal.[59] This includes gas welding and all forms of arc welding.[60] The area where the base and filler metals melt is called the weld pool or puddle.[61] The weld pool must be protected from oxygen in the air that will oxidize with the molten metal and from other gases that could contaminate the weld.[62] Most welding methods involve pushing the puddle along a joint to create a weld bead.[63] Overlapping pieces of metal can be joined by forming the weld pool within a hole made in the topmost piece of base metal to form a plug weld.[64] Solid-state welding processes join two pieces of metal using pressure.[65] Electric resistance welding is a common industrial process that combines heat and pressure to join overlapping base metals without any filler material.[66] Main article: Oxy-fuel welding and cuttingDiagram of oxyfuel welding: Torch tipFiller rodFlame (outer envelope)FusionBase metalWeld metalGas welding, also known as oxyacetylene welding, uses an open flame to generate heat and shield the weld. Compared to arc welding, the flame is less concentrated and lower in temperature, about 3100C (5600F) near the torch tip. This causes slower weld cooling, which can lead to greater residual stresses and weld distortion, though it eases the welding of high alloy steels. The diffuse outer envelope of the flame consumes oxygen before it can reach the molten weld pool.[30] When working with easily oxidized metals, such as stainless steel, flux can be brushed onto the base metals.[67]The equipment is relatively inexpensive and simple, consisting of a torch, hoses, pressure regulators, a tank of oxygen, and a tank of fuel (usually acetylene).[68] It is one of the oldest and most versatile welding processes, but it has become less popular in industrial applications. It is still widely used for welding pipes and tubes, as well as repair work.[30] A similar process, generally called oxyfuel cutting, is used to cut metals. Oxyfuel equipment can also be used to heat metal before bending or straightening.[69]Main articles: Arc welding, Shielded metal arc welding, Gas tungsten arc welding, Gas metal arc welding, Flux-cored arc welding, Submerged arc welding, and Electroslag weldingWelding seen from a welder's perspective through a shaded lens (left) and from the side without a shaded lens (right)[70]All arc welding processes use a welding power supply to create and maintain an electric arc between an electrode and the base material to melt metals at the welding point. They can use alternating current (AC) or direct current (DC). For DC welding, the electrode can be connected to the machine's positive terminal (DCEP) or negative terminal (DCEN), changing the current's direction. The process and type of electrode used will typically determine the current.[71][72] Shielding gas prevents oxygen in the atmosphere from entering the molten weld pool. In some processes, the shielding gas is delivered from gas cylinders containing inert or semi-inert gas. In others, a flux coating on a consumable electrode disintegrates to create the gas.[73][74] Filler material is typically added to the molten weld pool and is necessary for processes that use a consumable electrode.[75]Diagram of arc and weld area, in shielded metal arc welding: Flux coatingCore wireShield gasFusionBase metalWeld metalSolidified slagOne of the most common types of arc welding is shielded metal arc welding (SMAW);[76] it is also known as manual metal arc welding (MMAW) or stick welding. Electric current is used to strike an arc between the base material and consumable electrode rod, which is made of filler material (typical steel) and is covered with a flux that protects the weld area from oxidation and contamination by producing carbon dioxide (CO_2) gas during the welding process. The electrode core itself acts as filler material, making a separate filler unnecessary.[76]The process is versatile and can be performed with relatively inexpensive equipment, making it well suited to shop jobs and field work.[76][77] An operator can become reasonably proficient with a modest amount of training and can achieve mastery with experience. Weld times are rather slow, since the consumable electrodes must be frequently replaced and because slag, the residue from the flux, must be chipped away after welding.[76] Furthermore, the process is generally limited to welding ferrous materials, though special electrodes have made possible the welding of cast iron, stainless steel, aluminum, and other metals.[77]Gas metal arc welding:TravelContact tubeElectrodeShielding gasFusionWeld metalBase metal Gas metal arc welding (GMAW), also known as metal inert gas or MIG welding, is a semi-automatic or automatic process that uses a continuous wire feed as an electrode and an inert or semi-inert gas mixture to protect the weld from contamination. Since the electrode is continuous, welding speeds are greater for GMAW than for SMAW.[78]Flux-cored arc welding: Flux coreTubular electrodeShield GasFusionBase metalWeld metalSolidified slagA related process, flux-cored arc welding (FCAW), uses similar equipment but uses wire consisting of a tubular steel electrode surrounding a powder fill material. This cored wire is more expensive than the standard solid wire and can generate fumes and/or slag, but it permits even higher welding speed and greater metal penetration.[79] As the electrode is consumed, the flux disintegrates to create shielding gas and a protective layer of slag similar to stick welding. Some flux-cored machines have a nozzle that uses a shielding gas to supplement the protection from the flux. This is called dual shield welding, and uses a specialized gas shielded flux-core wire.[80]Gas tungsten arc weldingGas tungsten arc welding (GTAW), or tungsten inert gas (TIG) welding, is a manual welding process that uses a non-consumable tungsten electrode, an inert or semi-inert gas mixture, and a separate filler material.[81] Especially useful for welding thin materials, this method is characterized by a stable arc and high-quality welds, but it requires significant operator skill and can only be accomplished at relatively low speeds.[81]GTAW can be used on nearly all weldable metals, though it is most often applied to stainless steel and light metals. It is often used when quality welds are extremely important, such as in bicycle, aircraft and naval applications.[81] A related process, plasma arc welding, also uses a tungsten electrode but uses plasma gas to make the arc. The arc is more concentrated than the GTAW arc, making transverse control more critical and thus generally restricting the technique to a mechanized process. Because of its stable current, the method can be used on a wider range of material thicknesses than can the GTAW process and it is much faster. It can be applied to all of the same materials as GTAW except magnesium, and automated welding of stainless steel is one important application of the process. A variation of the process is plasma cutting, an efficient steel cutting process.[82]Submerged arc welding (SAW) is a high-productivity welding method in which the arc is struck beneath a covering layer of flux. This increases arc quality since contaminants in the atmosphere are blocked by the flux. The slag that forms on the weld generally comes off by itself, and combined with the use of a continuous wire feed, the weld deposition rate is high. Working conditions are much improved over other arc welding processes, since the flux hides the arc and almost no smoke is produced. The process is commonly used in industry, especially for large products and in the manufacture of welded pressure vessels.[83] Other arc welding processes include atomic hydrogen welding, electroslag welding (ESW), electrogas welding, and stud arc welding.[84] ESW is a highly productive, single-pass welding process for thicker materials between 1 inch (25mm) and 12 inches (300mm) in a vertical or close to vertical position.To supply the electrical power necessary for arc welding processes, a variety of different power supplies can be used. The most common welding power supplies are constant current power supplies and constant voltage power supplies. In arc welding, the length of the arc is directly related to the voltage, and the amount of heat input is related to the current. Constant current power supplies are most often used for manual welding processes such as gas tungsten arc welding and shielded metal arc welding, because they maintain a relatively constant current even as the voltage varies. This is important because in manual welding, it can be difficult to hold the electrode perfectly steady, and as a result, the arc length and thus voltage tend to fluctuate. Constant voltage power supplies hold the voltage constant and vary the current, and as a result, are most often used for automated welding processes such as gas metal arc welding, flux-cored arc welding, and submerged arc welding. In these processes, arc length is kept constant, since any fluctuation in the distance between the wire and the base material is quickly rectified by a large change in current. For example, if the wire and the base material get too close, the current will rapidly increase, which in turn causes the heat to increase and the tip of the wire to melt, returning it to its original separation distance.[85]The type of current used plays an important role in arc welding. Consumable electrode processes such as shielded metal arc welding and gas metal arc welding generally use direct current, but the electrode can be charged either positively or negatively. In welding, the positively charged anode will have a greater heat concentration, and as a result, changing the polarity of the electrode affects weld properties. If the electrode is positively charged, the base metal will be hotter, increasing weld penetration and welding speed. Alternatively, a negatively charged electrode results in more shallow welds.[86] Non-consumable electrode processes, such as gas tungsten arc welding, can use either type of direct current, as well as alternating current. However, with direct current, because the electrode only creates the arc and does not provide filler material, a positively charged electrode causes shallow welds, while a negatively charged electrode makes deeper welds.[87] Alternating current rapidly moves between these two, resulting in medium-penetration welds. One disadvantage of AC, the fact that the arc must be re-ignited after every zero crossings, has been addressed with the invention of special power units that produce a square wave pattern instead of the normal sine wave, making rapid zero crossings possible and minimizing the effects of the problem.[88]Main article: Resistance weldingResistance welding generates heat from electrical resistance in the base metals. Two electrodes are simultaneously used to press the metal sheets together and to pass current through the sheets. The electrodes are made from highly conductive material, usually copper. The higher resistance in the base metals causes small pools of molten metal to form at the weld area as high current (1,000100,000 A) is passed through.[89] Spot welderResistance spot welding is a popular method used to join overlapping metal sheets of up to 3mm thick. The advantages of the method include efficient energy use, limited workpiece deformation, high production rates, easy automation, and no required filler materials. Weld strength is significantly lower than with other welding methods, making the process suitable for only certain applications. It is used extensively in the automotive industryordinary cars can have several thousand spot welds made by industrial robots. In general, resistance welding methods are efficient and cause little pollution, but their applications are somewhat limited and the equipment cost can be high. A specialized process called shot welding, can be used to spot weld stainless steel.[89]Seam welding also relies on two electrodes to apply pressure and current to join metal sheets. However, instead of pointed electrodes, wheel-shaped electrodes roll along and often feed the workpiece, making it possible to make long continuous welds. In the past, this process was used in the manufacture of beverage cans, but now its uses are more limited.[89] Other resistance welding methods include butt welding,[90] flash welding, projection welding, and upset welding.[89]Energy beam welding methods, namely laser beam welding and electron beam welding, are relatively new processes that have become quite popular in high production applications. The two processes are quite similar, differing most notably in their source of power. Laser beam welding employs a highly focused laser beam, while electron beam welding is done in a vacuum and uses an electron beam. Both have a very high energy density, making deep weld penetration possible and minimizing the size of the weld area. Both processes are extremely fast, and are easily automated, making them highly productive. The primary disadvantages are their very high equipment costs (though these are decreasing) and a susceptibility to thermal cracking. Developments in this area include laser-hybrid welding, which uses principles from both laser beam welding and arc welding for even better weld properties, laser cladding, and x-ray welding.[91]Solid-state welding processes classification chart[92]Like forge welding (the earliest welding process discovered), some modern welding methods do not involve the melting of the materials being joined. One of the most popular, ultrasonic welding, is used to connect thin sheets or wires made of metal or thermoplastic by vibrating them at high frequency and under high pressure.[93] The equipment and methods involved are similar to that of resistance welding, but instead of electric current, vibration provides energy input. When welding metals, the vibrations are introduced horizontally, and the materials are not melted; with plastics, which should have similar melting temperatures, vertically. Ultrasonic welding is commonly used for making electrical connections out of aluminum or copper, and it is also a very common polymer welding process.[93]Another common process, explosion welding, involves the joining of materials by pushing them together under extremely high pressure. The energy from the impact plasticizes the materials, forming a weld, even though only a limited amount of heat is generated. The process is commonly used for welding dissimilar materials, including bonding aluminum to carbon steel in ship hulls and stainless steel or titanium to carbon steel in petrochemical pressure vessels.[93]Other solid-state welding processes include friction welding (including friction stir welding and friction stir spot welding),[94] magnetic pulse welding,[95] co-extrusion welding, cold welding, diffusion bonding, exothermic welding, high frequency welding, hot pressure welding, induction welding, and roll bonding.[93]Main article: Welding jointCommon welding joint types:Square butt jointV butt jointLap jointT-jointWelds can be geometrically prepared in many different ways. The five basic types of weld joints are the butt joint, lap joint, corner joint, edge joint, and T-joint (a variant of this last is the cruciform joint). Other variations exist as wellfor example, double-V preparation joints are characterized by the two pieces of material each tapering to a single center point at one-half their height. Single-U and double-U preparation joints are also fairly commoninstead of having straight edges like the single-V and double-V preparation joints, they are curved, forming the shape of a U. Lap joints are also commonly more than two pieces thickdepending on the process used and the thickness of the material, many pieces can be welded together in a lap joint geometry.[96]Many welding processes require the use of a particular joint design; for example, resistance spot welding, laser beam welding, and electron beam welding are most frequently performed on lap joints. Other welding methods, like shielded metal arc welding, are extremely versatile and can weld virtually any type of joint. Some processes can also be used to make multipass welds, in which one weld is allowed to cool, and then another weld is performed on top of it. This allows for the welding of thick sections arranged in a single-V preparation joint, for example.[97]The cross-section of a welded butt joint, with the darkest gray representing the weld or fusion zone, the medium gray the heat-affected zone, and the lightest gray the base material.After welding, a number of distinct regions can be identified in the weld area. The weld itself is called the fusion zonemore specifically, it is where the filler metal was laid during the welding process. The properties of the fusion zone depend primarily on the filler metal used, and its compatibility with the base materials. It is surrounded by the heat-affected zone, the area that had its microstructure and properties altered by the weld. These properties depend on the base material's behavior when subjected to heat. The metal in this area is often weaker than both the base material and the fusion zone, and is also where residual stresses are found.[98]Main article: Weld quality assuranceThe blue area results from oxidation at a corresponding temperature of 600F (316C). This is an accurate way to identify temperature, but does not represent the HAZ width. The HAZ is the narrow area that immediately surrounds the welded base metal.Many distinct factors influence the strength of welds and the material around them, including the welding method, the amount and concentration of energy input, the weldability of the base material, filler material, and flux material, the design of the joint, and the interactions between all these factors.[99]For example, the factor of welding position influences weld quality, that welding codes & specifications may require testingboth welding procedures and weldersusing specified welding positions: 1G (flat), 2G (horizontal), 3G (vertical), 4G (overhead), 5G (horizontal fixed pipe), or 6G (inclined fixed pipe).To test the quality of a weld, either destructive or nondestructive testing methods are commonly used to verify that welds are free of defects, have acceptable levels of residual stresses and distortion, and have acceptable heat-affected zone (HAZ) properties. Types of welding defects include cracks, distortion, gas inclusions (porosity), non-metallic inclusions, lack of fusion, incomplete penetration, lamellar tearing, and undercutting.The metalworking industry has instituted codes and specifications to guide welders, weld inspectors, engineers, managers, and property owners in proper welding technique, design of welds, how to judge the quality of welding procedure specification, how to judge the skill of the person performing the weld, and how to ensure the quality of a welding job.[99] Methods such as visual inspection, radiography, ultrasonic testing, phased-array ultrasonics, dye penetrant inspection, magnetic particle inspection, or industrial computed tomography can help with detection and analysis of certain defects.The heat-affected zone (HAZ) is a ring surrounding the weld in which the temperature of the welding process, combined with the stresses of uneven heating and cooling, alters the heat-treatment properties of the alloy. The effects of welding on the material surrounding the weld can be detrimentaldepending on the materials used and the heat input of the welding process used, the HAZ can be of varying size and strength. The thermal diffusivity of the base material plays a large roleif the diffusivity is high, the material cooling rate is high and the HAZ is relatively small. Conversely, a low diffusivity leads to slower cooling and a larger HAZ. The amount of heat injected by the welding process plays an important role as well, as processes like oxyacetylene welding have an unconcentrated heat input and increase the size of the HAZ. Processes like laser beam welding give a highly concentrated, limited amount of heat, resulting in a small HAZ. Arc welding falls between these two extremes, with the individual processes varying somewhat in heat input.[100][101] To calculate the heat input for arc welding procedures, the following formula can be used: $Q = (V I 60 S 1000) E f f i c i e n c y$ {\displaystyle Q=\left({\frac {V\times I\times 60}{S\times 1000}}\right)\times {\mathit {Efficiency}}} where Q = heat input (kJ/mm), V = voltage (V), I = 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.[102] Methods of alleviating the stresses and brittleness created in the HAZ include stress relieving and tempering.[103]One major defect concerning the HAZ is cracking at the junction of the weld face and the base metal. Due to the rapid expansion (heating) and contraction (cooling), the material may not have the ability to withstand the stress and could crack. One method to control the stress is to control the heating and cooling rate, such as pre-heating and post-heating [104]Example: High Frequency Impact Treatment for lifetime extensionThe durability and life of dynamically loaded, welded steel structures is determined in many cases by the welds, in particular the weld transitions. Through selective treatment of the transitions by grinding (abrasive cutting), shot peening, High-frequency impact treatment, Ultrasonic impact treatment, etc. the durability of many designs increases significantly.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.[105]Crystalline solids cohesion is obtained by a metallic or chemical bond that 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.[105]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.[105]Metallic bonding can be classified as a type of covalent bonding for which the constituent atoms are 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.[105]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 aluminium, copper and nickel have the face-centred cubic structure.[105]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.[105]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.[105]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 74481; The J integral test per ASTM E1820; The Pellini drop-weight test per ASTM E208.[105]Underwater weldingWhile 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 possibleit was first attempted in 1969 by Russian cosmonauts during the Soyuz 6 mission, 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.[106]A stick welding booth equipped with local exhaust system (LEV) that removes the toxic fumes, gases, vapours and dusts before they can mix with the room air. Besides toxic emissions, the booth also helps protect bystanders from UV light. With a well-ventilated booth, personal protective equipment is still needed for the welder.Arc welding with a welding helmet, gloves, and other protective clothing (1942)Welding can be dangerous and unhealthy if the proper precautions are not taken.[107] Potential safety risks come from fumes, ultraviolet radiation, heat, electric currents, and vibrations.[108] New technology, safe work practices, and proper protection reduce the risks of injury or death from welding.[109]Since many common welding procedures involve an open flame or electric arc, 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. Synthetic clothing such as polyester should not be worn.[110] Wool is less flammable than cotton, but dense cotton fabrics such as denim are still sufficient for clothing. However, any molten material that splatters onto synthetic material will melt directly through the fabric resulting in severe burns.[111]Arc welding produces intense visible and ultraviolet light. Typical gas metal arc welding has an irradiance of 5W/m2 for the welder, which is many times brighter than sunlight.[112] This can cause 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. Welding helmets with dark UV-filtering face plates are worn to prevent this exposure.[113] Many helmets include an auto-darkening face plate, which instantly darkens upon exposure to the intense UV light.[114][115] To protect bystanders, the welding area is often surrounded by 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 they cannot replace the filter glass used in helmets.[116] The light can also burn exposed skin.[117] Because of the less intense light produced in oxyfuel welding, goggles that use less UV filtering and do not protect the entire face are sufficient.[118]Depending on the type of material, welding varieties, and other factors, welding can produce over 100dB(A) of noise.[119] Above 85dB(A), earplugs should be worn.[120] Long-term or continuous exposure to higher decibels can lead to noise-induced hearing loss.[121] Processes that produce vibrations sufficient to numb a welder's hands are automated because PPE cannot offer sufficient protection.[122]A chamber designed to contain welding fumes for analysisA video describing research on welding helmets and their ability to limit fume exposureWelders 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 can cross the bloodbrain barrier. Fumes and gases, such as carbon dioxide, ozone, and fumes containing heavy metals, can be dangerous to welders lacking proper ventilation and training.[123] Exposure to manganese welding fumes, for example, even at low levels (