BRAZING
&
CASE IRON REPAIR

CARSON BUSINESS UNIT
TRAINING
DEPARTMENT

STUDENT GUIDE

DISCLAIMER

This reference material is intended as collateral support for this course. This material has been assembled as part of a comprehensive training program in order to provide a common base of technical knowledge for the class participant.

This material is not intended for use as a field operating manual nor is it intended as a substitute for any process instruction or standard operating or company safety procedures.

The sample content of this notebook represents the information available from companies that provide brazing and cast iron repairs.

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Tabs & Table of Contents

SAFETY

The following is a list of some safety items that should be followed when using an Oxy-Acetylene outfit.

1. Never use Acetylene gas at a pressure over 15 psig.
2. Never use damaged equipment.
3. Never use oil or grease on or around Oxygen equipment.
4. Never use Oxygen or fuel gas to blow dirt or dust off clothing or equipment.
5. Never light a torch with matches or a lighter. Always use a striker.
6. When opening a Oxygen or fuel cylinder valve, always crack it open first.
7. Always make sure regulators have their adjusting screws released by turning them counter clockwise till free before opening cylinder valves. Stand to the side of a regulator, not in front of it when opening cylinder valves.
8. Always wear the proper welding goggles, gloves and clothing when operating Oxy-Acetylene equipment. Pants should not have cuffs.
9. Always have a fire extinguisher handy when operating Oxy-Acetylene equipment.
10. Always replace cylinder caps when finished using cylinders.
11. Do not rely on the color of the cylinder to identify its contents as some suppliers may use different color codes.
12. Always use the proper regulator for the gas in the cylinder.
13. Always use cylinders in the upright position only.
14. Never store cylinders in temperatures over 130deg. F.
15. Always keep the valve wrench on the Acetylene cylinder valve when in use. Only open valve a maximum of 1 1/2 turns.
16. Do not carry lighters, matches or other flammable objects in pockets when welding or cutting.
17. Always be aware of others around you when using a torch.
18. Be careful not to let welding hoses come into contact with torch flame or sparks from cutting.

Safety in Brazing

In brazing, there is always the possibility of dangerous fumes and gases rising from base metal coatings, ink and cadmium-bearing filler metals, and from fluorides in fluxes. The following well-tested precautions should be followed to guard against any hazard from these fumes.

1. Ventilate confined areas. Use ventilating fans and exhaust hoods to carry all fumes and gases away from work, and air supplied respirators as required.
2. Clean base metals thoroughly, A surface contaminant of unknown composition on base metals may add to fume hazard and may cause a too rapid breakdown of flux, leading to over heating.
3. Use sufficient flux. Flux protects base metals and filler metal during heating cycle. Full flux coverage reduces fuming, Also, consult your MSDS regarding specific hazards associated with brazing flux.
4. Heat metals broadly. Heat the base metals broadly and uniformly. Intense localized heating uses up flux, increases danger of fuming.
5. Know you base metals. A cadmium coating on a base metal volatilize and produce toxic fume during heating. Zinc coatings (galvanized) will also fume when heated. Learn to recognize these coatings. It is recommended that they be removed before parts are heated for brazing.
6. Know you fill metals. Be especially careful not to overheat assembly when using filler metals that contain cadmium. Consult the Material Safety Data Sheet for maximum recommended brazing temperatures of a specific filler metal. The filler metal carries a warning label. Be sure to look for it and follow the instructions.

(For safety considerations, see the American National Standard Z49.1, "Safety in Welding and Cutting", published be the American Welding Society (AWS), 550 N.W. LeJeune Rd., Miami, Florida 33126.)

Recommended pickling solutions for post-braze removal of oxides

The pickling solutions recommended below may be used to remove oxides from areas that were not protected by flux during the brazing process. In general, they should be used after the flux residue has been removed from the brazed assembly.

Safety in Brazing

Brazing, Welding, and Soldering are hazardous activities that could pose serious health threats to all the workers of these industries. There is always the possibilities of harmful gases and fumes rising from the base metal coverings, cadmium containing filler metals, inks, and also from fluorides present in the fluxes. These dangerous by-products are formed in most of the industries in one form or another. They seriously affect the respiratory and nervous system of the people working in that environment. Apart from it they also affect the skin, eyes, hairs, and other body parts.

There are some well-tested precautions that should be followed to guard against the hazards from these fumes.

- **Proper Ventilation**

The brazing process produces a large number of hazardous fumes and gases, which are serious threats to human life. These dangerous fumes should be expelled from the working area. So the confined areas should be ventilated properly. You can use ventilating fans and exhaust hoods to expel all fumes and gases away from working area.

- **Clean The Base Metals**

  The base metals should be cleaned thoroughly before use. The unknown contaminants, of unknown composition, deposited on the surface of base metals can add to fume hazard. They may cause over heating of the flux leading to a rapid breakdown

- **Know The Metals**

  You should thoroughly know the metals you are going to braze. During heating the cadmium coated base metals tend to volatilize and produce toxic fumes. The galvanized or zinc coated metals also produce fumes when heated. You must learn to recognize these coatings and the hazards. They should be removed before parts are heated for brazing

- **Sufficient Flux**
  The amount of flux should be sufficient. The main use of flux is to protect the base metals and filler metal during the heating cycle. It helps in reducing the fuming.

- **Know The Fillers**
  Don't overheat the assembly when using filler metals or alloys that contain cadmium. You must follow the related material safety data sheet for maximum recommended brazing temperatures of a specific filler metal.

Pickling Solutions for Oxide Removal

The brazing process is hugely affected by the formation of oxides on the surface of metals. The layers of oxides create problems for efficient and strong bonding. The pickling solutions are used to remove oxides from the areas which were not protected by flux during the brazing process. A number of pickling solutions are available for this purpose

Application	Formulation	Comments
Copper, Bronze, Nickel, Silver, Brass and other alloys containing high percentages of copper	10 to 25% hot H2SO4 (Sulphuric Acid) with 5 to 10% K2Cr2O7 (potassium di-chromate) added	Pickling is done after the removal of flux. It will work on carbon steels. If pickle is contaminated with copper, the copper will plate out on the steel, thus needs mechanical removal. This sulphuric pickle is an oxidizing pickle, which will remove copper or cuprous oxide stains from the copper alloys.
Irons and Steels	Hot or cold 50% hydrochloric acid (HCl) solution. Diluted acid (10 to 25%) can also be used at higher temperatures (140°F-160°F).	For Monel and other nickel alloys, a mixture of 1 part hydrochloric acid to 2 parts water can be used. The Pickling solution should be heated to 180°F (80°C). For bright finishing, mechanical finishing is essential.
Stainless steels and Chromium Alloys	20% H2SO4, 20% HCl, 60% water, used at a temperature of 170-180°F(75-80°C.)	This pickle is followed directly by a 10% nitric dip, and then a clean water rinse.

General Safety Methods

- Oil, grease, and other combustible materials shouldn't be placed near the gas cylinders. Other substances, such as reserve stocks of carbide and acetylene, other fuel gas cylinders should be kept away from the substance likely to cause or accelerate fire.

- Cylinders shall be stored in a well-ventilated, well-protected, dry location at a minimum distance of 20 feet from highly combustible materials such as oil or excelsior. They should be stored in definitely assigned places away from stairs, gangways, and elevators.

- The storage spaces shall be situated where cylinders will not be damaged by passing or falling objects. It should be saved from tampering by unauthorized persons.

- The empty fuel or gas cylinders shall have their valves closed.

- The workers or other persons nearby the brazing equipment shall be protected by noncombustible or flame-proof screens or shields. The screens mustn't not impede ventilation.

- Cables used shouldn't have damaged insulation or exposed bare conductors.

PHYSICAL PROPERTIES OF METALS

What is a metal? Technically, it is an element which has the following properties: – It is solid at room temperature (mercury is an exception) – It is opaque (that is, you can't see through it) – It conducts heat and electricity – It reflects light when polished – It expands when heated, contracts when cooled – It usually has a crystalline structure Some metals – gold, silver, copper, and zinc, for example – are often used in essentially pure form. However, most metals used for industrial purposes are actually alloys, not pure metals. An alloy is a metal to which another metal (or metals), or a non-metallic element such as carbon or silicon, has been added to modify the physical or mechanical properties of the pure metal. Iron, aluminum, titanium, and magnesium are used predominantly in alloy form. Pure iron, in fact, is something of a laboratory curiosity. Steel and cast iron are properly considered alloys of iron. Even though a low-carbon steel may contain more than 99% iron, and not more than 0.30% carbon, that little bit of carbon makes a lot of difference. The distinction between ”metal” and ”alloy” is seldom observed in the everyday world, since alloys always have the general properties listed above as applying to metals. When we speak of “low-alloy” or “high alloy” steels we are not overlooking the fact that steel is an alloy of iron and carbon; instead, we are indicating that the low-alloy steel includes relative small percentages of other metals, and that high-alloy steels contain substantial amounts of other metals (most frequently, chromium or nickel).

This chapter will cover what are termed the physical properties of metal. Chapter 8 will be devoted to the mechanical properties of metals, with emphasis on steel. The physical properties of a material are properties not related to the ability of the material to withstand external mechanical forces, such as pushing, pulling, twisting, bending, etc. These properties include density, melting point, specific heat, heat of fusion, thermal conductivity, thermal expansion, electrical conductivity, and corrosion resistance.

Density. The measure of unit mass; in everyday terms, the weight of a unit volume. Density is variously expressed as grams per cubic centimeter (g/cm^3), kilograms per cubic meter (kg/m^3), pounds per cubic inch ($lb. /in.^3$), pounds per cubic foot ($lb./ft.^3$). For comparative purposes, density is often expressed as *specific gravity,* the ratio of the density of the material to the density of water. The specific gravity of aluminum is 2.70 – in other words, it is nearly three times as heavy as water. Iron has a specific gravity of 7.86; for gold, the value is 19.3.

Melting Point. Every pure metal has a specific melting point. If you apply heat to a solid specimen, its temperature will rise until it reaches that melting point. It will then start to melt, and it will remain at the melting point temperature, even though the heating is continued, until the specimen is completely melted. Then, and only then, will the temperature of the liquid metal start to rise once more. The amount of heat required to melt a unit mass of metal includes the heat required to raise that mass to its melting point, and the additional quantity of heat required to accomplish complete melting once the melting point has been reached.

Melting Point of Alloys. Most alloys do not melt completely at a specific temperature. Melting starts when the material has reached a certain temperature, but is not completed until a somewhat higher temperature has been reached. This is a fact of great significance in the welding of steel; we'll get into this more deeply in Chapter 10, and when we get to talk about the practice of welding.

Specific Heat. The amount of heat required to raise a unit mass of solid metal one degree in temperature is termed *specific heat.* The lighter the metal, the greater the specific heat. In other words, it takes more heat to raise the temperature of one kilogram of aluminum one degree than it takes to raise the temperature of one kilogram of iron one degree.

Heat of Fusion.

The amount of heat required to completely melt a unit mass of a metal once it has attained its melting point. Here again, more heat is required for a light metal, such as aluminum, than for a heavier metal such as iron.

Thermal Conductivity. As everyone knows, the handle of a sterling silver spoon left in a hot cup of coffee gets hot in a hurry, whereas a stainless steel spoon handle heats up only a little in the same period of time. Silver is an excellent conductor of heat, while stainless steel is a poor conductor. In fact, silver is twice as good a conductor as aluminum, and nearly 10 times as good as a conductor as low-carbon steel. Copper and gold are the only metals that come close to silver in thermal conductivity. In fact, the high conductivity of copper is quite a complication when it comes to welding.

Thermal Expansion.

The increase in dimensions of a solid body due to an increase in temperature is termed *thermal expansion.* This property is of much significance in welding operations, since the metal close to the weld zone is heated to a higher temperature, and therefore expands more than the metal at a greater distance from the weld zone. Furthermore, the molten metal deposited during welding must shrink – or least try to shrink – as it cools down in the solid state. Mathematically, the term used to express the tendency of a metal to expand when heated is "coefficient of thermal expansion”. By comparison with zinc, lead, and magnesium, this coefficient is relatively small for steel; an iron bar one meter long increases in length a little more than one millimeter when heated 100^0C. The expansion and contraction of steel when heated and cooled are matters of great importance in welding.

Electrical Conductivity. As stated earlier, a metal must be a conductor of electricity. Some are much better than others; generally, the metals which are the best conductors of heat, such as copper, silver and aluminum, are also the best conductors of electricity.

Corrosion Resistance.

To some extent, the ability of a given metal to resist corrosion is a *chemical* rather than a physical property, since it is at least partially determined by purely chemical factors. However, we can properly mention it here because the corrosion resistance of an alloy is often determined as much by the physical crystalline structure of the alloy as by the chemical nature of its components. For example, stainless steel composed of about 74% iron, 18% chromium, and 8% nickel is virtually immune to attack by some liquids which would rapidly eat away low-carbon steel (99% iron). Why this is true is beyond the scope of this book. Let’s be thankful, however, that it is and that for many purposes we can use an alloy which is largely iron and get almost the same corrosion resistance we could expect from more expensive pure nickel.

MECHANICAL PROPERTIES OF METALS

The **mechanical properties** of a material are those related to its ability to withstand external mechanical forces such as pulling, pushing, twisting, bending, and sudden impact. In general terms, we think of these properties as various kinds of “strength”. However, the word “strength”, used alone, don’t tell us very much. Steel, cast iron, rubber, and glass are each “strong” in different ways.

Tensile Strength, Elasticity, and Ductility

In the field of metals, when the word “strength” is used alone (as in “high-strength steels”) it almost always refers to the ability of the metal to resist pulling force; specifically, to what is termed its tensile strength. If we start by considering what happens when a bar of steel is subjected to a steadily-increasing pull, we cannot only define tensile strength, but also yield strength, elasticity, and ductility. It’s obvious that it will take more pull to break a steel bar with a cross-sectional area of 10 square centimeters (10 cm^2) than to break one with a cross-sectional area of 5 cm^2, so we must start with a specimen having a precisely-determined cross-sectional area if the results are to yield useful data. This specimen is secured firmly in a tensile testing machine which is capable of applying all the pulling force needed to break it. The machine is equipped with gauges which will show both the force being applied and the increase in length of the specimen as force is applied. The force can be mathematically converted to stress by applying the known minimum cross- sectional area of the specimen. (Stress equals force divided by area.)* *In the “English” system of measurement, force has been expressed in pounds, stress in pounds per square inch (psi). In the metric system, until recently, force was expressed in kilograms, stress in kilograms per square centimeter (kg/cm^2). In the updated metric system (SI), force is expressed in newtons (N), stress in pascals (Pa). (One newton, acting across an area of one square meter, equals one pascal). Tensile strengths will usually be stated in megapascals (MPa) (millions of pascals).

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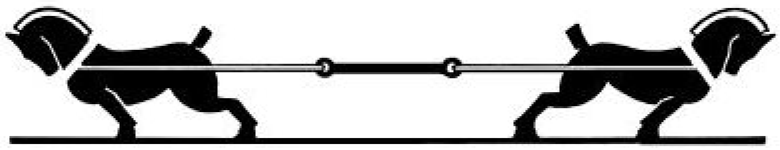


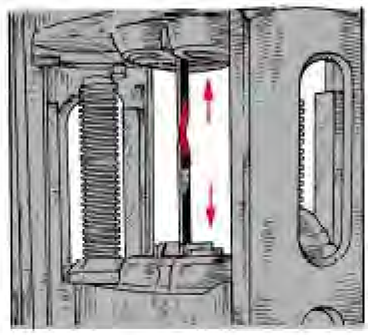
Tensile strength is expressed in terms of the directly-applied pull required to break apart.

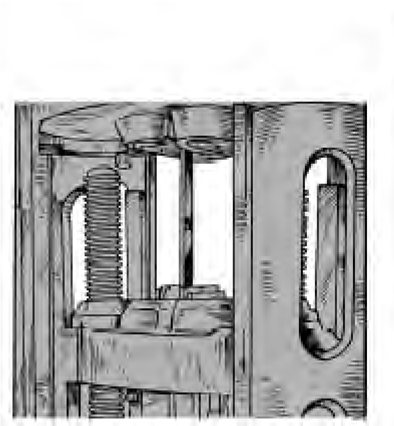
As the machine pulls the specimen, it stretches – not a great deal, but enough to register on the strain gauge. If we gradually increase the pulling force, the amount of strain will also increase. A force of 20 kilonewtons (4500 lb.) will cause twice the strain produced by a force of 10 kilonewtons (2250 lb.). The steel is *elastic.* Until the *elastic limit* of the specimen has been reached, the amount of strain will be directly proportional to the amount of pull, and the specimen will always return to its original length if the pulling force is released.

If we continue to apply pulling force at a gradually increasing rate, watching both the force and strain gauge hands closely, we reach a point where the strain gauge hand continues to move while the force gauge hand remains stationary, or even drops a bit. We have now reached the elastic limit of the steel. If at this point, the pulling force is released, the specimen will not return to its original length. It has undergone permanent deformation. The force required to produce a slight amount of permanent deformation, expressed as megapascals (MPa) or pounds per square inch (psi) of specimen cross-section, is termed yield point or yield strength. If, instead of releasing the pulling force when the yield point has been reached, we continue to increase that force, the test specimen will stretch at a more rapid rate until the pulling force reaches a maximum point. Then it will begin to “neck down” or grow visibly narrower at some point; the force gauge hand will start to drop, while the hand on the strain gauge will continue to climb. Then the specimen will break, after “necking down” substantially. The value established by the highest reading registered on the force gauge is termed the tensile strength or ultimate tensile strength of the steel. To be more specific:

The ultimate tensile strength is the maximum force registered on the testing machine divided by the original cross-sectional area of the specimen. The force registered at the instant of breakage, divided by the final cross-section area of the specimen at the point of breakage, is termed the fracture strength. In steel, fracture strength, while of little practical significance, almost always has a higher value than ultimate tensile strength. Permanent deformation of steel increases its unit tensile strength. That’s why steel wire, which is repeatedly deformed as it is drawn, is stronger (in terms of breaking force per unit of cross-section) than a steel bar from the same heat of steel, and why cold-rolled steel is stronger than hot-rolled steel.

This coupon has started to ”neck down” outside the weld zone. The weld is good





Tensile strength of a weld coupon can be determined by pulling the coupon until it breaks

Let’s now try to define more precisely the several terms just introduced in describing the tensile testing of a steel bar.

Yield Strength.

The tensile force required to cause a slight but well-defined permanent deformation.

Yield Point.

The force level at which strain (elongation) takes place without any increase in stress (pull).

Elastic Limit.

The force required to produce permanent deformation. For all practical purposes, when dealing with ordinary low-carbon structural steels, yield strength, yield point, and elastic limit have the same values.

Ultimate Tensile Strength.

The maximum strength of the material in terms of its original cross-sectional area. For engineering purposes, this is the value that can be used to determine the maximum load which a structural member should withstand without breaking. For many purposes, yield strength is the more significant value, since appreciable permanent deformation (stretching) will usually occur before stress has reached ultimate strength value.

Elasticity.

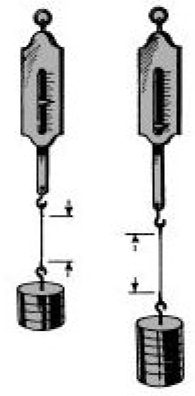
The linear relationship of non-permanent change in length to the force applied (in other words, the relationship of strain to stress). Rubber is extremely elastic; many metals are more elastic than steel in that a given pull will produce a greater increase in length. Cast iron, in this sense, is actually twice as elastic as steel. However, don’t forget that the important value, when dealing with metals, is usually the elastic limit, not the modulus of elasticity (relation of strain to stress below the elastic limit).

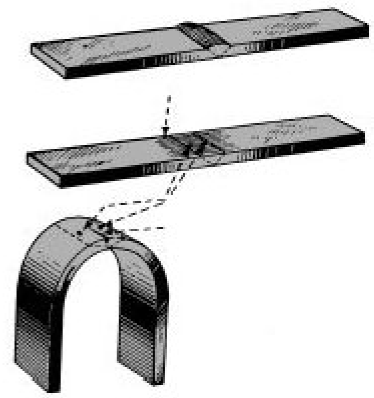
Ductility.

Elasticity deals with the relationship of non-permanent strain to stress. Ductility is a measure of the ability of a material to undergo permanent deformation without breaking. Copper and aluminum are extremely ductile, generally speaking. Most low-carbon steels are quite ductile. Some cast irons have virtually no ductility; to put it in simple terms, they break before they bend. All types of steel have approximately the same degree of *elasticity;* that is, up to the elastic limit, the stress-strain relationship is the same, regardless of composition. However, ductility varies greatly, depending not only on composition but on several other factors as well. Ordinary low-carbon steels are moderately ductile; high-carbon tool steels have little ductility. Ductility is usually expressed as “percent elongation in two inches” or as ”percent reduction in cross-section area”. If, before we started the test just described, we had placed two marks on the test specimen, precisely five centimeters (5 cm) apart, we could establish the percent elongation by fitting the pieces of the specimen together, after breaking, and then measuring the new distance between the two marks. In the case of low-carbon steel, we might find that the elongation was 30% (that is, from 5 cm to 6.5 cm). If the original cross-section of the specimen had been two square centimeters (2 cm^2) and the cross-section, re-measured at the point of the break, turned out to be 1 cm^2, we could state that the reduction in area was 50%.

To check on the ductility of welds in steel plate, another method of arriving at “percent elongation” is sometimes used. After the weld has been completed, it is ground flush with the surface of the base metal, and two small punch marks made in the actual weld metal. The specimen is then placed in a vise, and bent until the first crack appears in the surface of the weld metal between the two marks. By using a flexible steel rule, the distance between the punch marks is measured and compared with the original distance between the two punch marks.

A way to measure the ductility of weld metal. (See description above).





A simple way to measure the ductility of wire. Grinding marks Gauge marks Crack starting Stretch continues Permanent stretch begins 1 ft 1 ft 2 in. Load A B C

While low-carbon steels exhibit relatively high ductility as measured by the methods described above, they are also subject to brittle failure under some conditions. A structural member may break suddenly when subject to stress which is below the expected yield point of the metal – that is, before any measurable permanent deformation has taken place. Such failure (fracture) always starts at a slight crack or notch in the metal. The ability of a steel to resist this type of fracture is termed notch ductility. Notch ductility is somewhat dependent on the composition of the steel. It is always related to temperature, (all steels lose notch ductility rapidly as temperatures drop below the 0-20^{0}C range) and to the grain structures within the steel, especially the structures which are formed as the result of welding. Stress-relieving – the reheating of the weld zone to a temperature of not more than 600^{0}C – is widely used to reduce the possibility of brittle fracture in welded structures.

Hardness

Where metals are involved, hardness is usually defined as the ability of the metal to resist indentation or penetration by another material. In itself, the exact hardness of a steel is not of great importance in most applications. However, hardness can be measured much more readily than can tensile strength, there is a very close relationship between hardness and tensile strength, and between hardness and ductility. Usually, the harder the steel, the higher its tensile strength, and the lower its ductility. Three methods of hardness testing are widely used: The Brinell method, in which a steel ball is forced against the surface of the specimen by a heavy load, and hardness determined by measuring the diameter of the impression left in the surface; the Rockwell method, in which a diamond cone is pressed into the surface, and hardness determined by a gauge, built into the testing unit, which registers the depth of the impression; and the Scleroscope method, in which a diamond-pointed cylinder of steel is dropped onto the surface of the material from a fixed height, and hardness determined by measuring the height of the rebound. Continued on next page...

The springs or elastic bands which secure this punching bag to floor and ceiling are being subjected to repeated, but not alternating, stress.

Other Kinds of ”Strength” Compressive Strength.

This may be thought of as the opposite of tensile strength: in other words, the ability of a material to resist a gradually applied “push”, rather than “pull”. Most metals have at least as much strength in compression as in tension, so that exact values for compressive strength are seldom significant.

Fatigue Strength.

Here is a property of great importance in the design of many parts and structures. All metals will fail under repeatedly changing load conditions at a lower stress than they will if the load is applied steadily in one direction. A wire that might support a continuous load of 5000 MPa indefinitely will probably fail in time if a load of 3000 MPa is alternately and repeatedly imposed and then released. The piston rod on a steam locomotive is subjected to tension for a half-cycle, then to compression for a half-cycle, thousands of times every day. Structural members in a bridge are constantly subject to changing load conditions. In all such applications, fatigue strength, which is always lower than tensile strength and sometimes **much** lower, must be considered by a designer. In addition to factors in the internal structure of a metal which cause it to become weaker when subjected to repeated changes in load, metal surface conditions are closely related to fatigue strength. Fatigue failure usually starts with a small crack; any roughness in the surface of a metal which might make it easier for such a crack to start – even slight pitting from a corrosive atmosphere can substantially reduce the fatigue strength. Fatigue strength is usually expressed as **fatigue limit** or **endurance limit**; both terms mean the same thing: the stress to which the material can be subjected indefinitely, under *varying* load conditions, before failure. If someone says that the fatigue limit of steel from a certain heat is 140 MPa (about 20,000 psi) assume he means that the steel can be subjected to repeated alternation of stress, from 140 MPa tension to 140 MPa compression, for at least 10,000,000 cycles without failure. However, values for fatigue strength are often expressed in more limited terms; for example, that the material will withstand “100,000 cycles of 300 MPa tension to 0 tension”, or “2,000,000 cycles of 125 MPa, reversed” (meaning that a complete cycle ranges from 125 MPa tension to 125 MPa compression).

The springs or elastic bands which secure this punching bag to floor and ceiling are being subjected to repeated, but not alternating, stress

The piston rod in this double air pump is being subjected to alternating stress. Each half of the rod is first pulled, then pushed. At some point in each cycle, stress in one half of the rod is zero

Impact Strength; Fracture Toughness.

Both of these terms refer to the ability of a material to withstand shock, or large forces suddenly applied. Neither property can be defined mathematically, for engineering use, in the same sense that tensile strengths can be defined. Impact strength is usually stated in terms of the energy absorbed by a metal when it is broken under carefully-defined and limited conditions. In the Charpy V-notch impact test, a specimen of fixed dimensions, which has been precisely notched, is broken by a blow from a pendulum hammer.

The difference between the distance which the hammer travels after breaking the specimen, and the distance it would have travelled had there been no specimen to hit, is a direct measure of the energy absorbed by the specimen before it fractured. This energy, expressed as units of force, is correctly described as impact energy, rather than impact strength. Two steels which have equal tensile strengths at room temperatures may vary widely in their impact energies (strengths) especially when tested at low temperatures.

Fracture toughness refers specifically to the resistance of a material to rapid crack propagation (the brittle fracture mentioned earlier) when a slight crack already exists and a massive load is applied suddenly. For a homely example, think of a loaded grocery bag sitting on the floor. If the bottom of the bag has no holes or tears, you can usually yank it up suddenly without mishap. If there is a small break in the bottom of the bag, you can often lift the bag slowly and get your arm under it, but if you try to yank it up, you’re likely to wind up with groceries scattered on the floor. Similarly, a very small crack in a metal member, which might reduce the strength of that member only slightly were high tensile stress to be created gradually, can sometimes spread with great speed, and destroy the member completely, when an equal load is applied suddenly. Fracture toughness depends on several factors which are not directly involved in the standard Charpy V-notch test, so the results of such tests are often considered only a rough measure of fracture toughness.

There are four basic types of cast iron

- white iron
- gray iron
- ductile iron
- malleable iron

White Cast Iron

Characterized by the prevalence of carbides, impacting

- high compressive strength
- hardness
- good resistance to wear

Gray Cast Iron

Characterized with graphite in the microstructure, giving

- good machinability
- good resistance to wear and galling

Ductile Cast Iron

Gray iron with small amounts of magnesium and cesium which nodulates the graphite, resulting

- high strength
- high ductility

Malleable Cast Iron

White cast iron heat-treated to improve

- higher ductility

Guidelines for Welding Cast Iron

Background

Cast iron is difficult, but not impossible, to weld. In most cases, welding on cast iron involves repairs to castings, not joining casting to other members. The repairs may be made in the foundry where the castings are produced, or may be made to repair casting defects that are discovered after the part is machined. Mis-machined cast iron parts may require repair welding, such as when holes are drilled in the wrong location. Frequently, broken cast iron parts are repaired by welding.

Broken cast iron parts are not unusual, given the brittle nature of most cast iron.

While there are a variety of types of cast iron, the most common is gray cast iron, and these guidelines are directed toward this type of material.

A few facts about cast iron help in understanding the welding challenges. Cast iron typically has a carbon content of 2% - 4%, roughly 10 times as much as most steels. The high carbon content causes the carbon to form flakes of graphite. This graphite gives gray cast iron its characteristic appearance when fractured.

When castings are made, molten iron is poured into a mold and allowed to slowly cool. When this high carbon material is allowed to cool slowly, crack free castings can be made. **Remembering this is helpful when welding cast iron: during and after welding, the casting must either be allowed to cool slowly, or should be kept cool enough that the rate of cooling is not important.**

A critical temperature in most cast iron is about 1450 degrees F. When at this temperature, conditions that can lead to cracking occur. While the arc will heat the casting to temperatures above this level, it is important that the casting not be held at this temperature for long periods of time.

Electrode selection

If the part is to be machined after welding, a nickel-type electrode will be required. Use Lincoln Softweld® 99Ni stick electrode for single pass, high dilution welds. Softweld 55 Ni is preferred for multiple pass welds. Sometimes, root passes are put in with Softweld 99 Ni, followed by fill passes with Softweld 55 Ni. For welds where machining is not required, and where the weld is expected to rust like the cast iron, Lincoln Ferroweld® stick electrode can be used.

To Heat, or not to Heat

In general, it is preferred to weld cast iron with preheat--and lots of it. But, another way to successfully weld cast iron is to keep it cool--not cold, but cool. Below, both methods will be described. However, **once you select a method, stick with it. Keep it hot, or keep it cool, but don't change horses in the middle of the stream!**

Welding Techniques with Preheat

Preheating the cast iron part before welding will slow the cooling rate of the weld, and the region surround the weld. It is always preferred to heat the entire casting, if possible. Typical preheat temperatures are 500-1200 degrees F. Don’t heat over 1400 degrees F since that will put the material into the critical temperature range. Preheat the part slowly and uniformly.

Weld using a low current, to minimize admixture, and residual stresses. In some cases, it may be necessary to restrict the welds to small, approximately 1-inch long segments to prevent the build up of residual stresses that can lead to cracking. Peening of weld beads can be helpful in this regard as well.

After welding, allow the part to slowly cool. Wrapping the casting in an insulating blanket, or burying it in dry sand, will help slow cooling rates, and reduce cracking tendencies.

Welding Techniques without Preheat

The size of the casting, or other circumstances, may require that the repair be made without preheat. When this is the case, the part needs to be kept cool, but not cold.

Raising the casting temperature to 100 degrees F is helpful. If the part is on an engine, it may be possible to run it for a few minutes to obtain this temperature. Never heat the casting so hot that you cannot place your bare hand on it.

Make short, approximately 1” long welds. Peening after welding is important with this technique. Allow the weld and the casting to cool. Do not accelerate the rate of cooling with water or compressed air. It may be possible to weld in another area of the casting while the previous weld cools. All craters should be filled. Whenever possible, the beads should be deposited in the same direction, and it is preferred that the ends of parallel beads not line up with each other.

Sealing Cracks

Because of the nature of cast iron, tiny cracks tend to appear next to the weld even when good procedures are followed. If the casting must be water tight, this can be a problem. However, leaking can usually be eliminated with some sort of sealing compound or they may rust shut very soon after being returned to service.

The Studding Method

One method used to repair major breaks in large castings is to drill and tap holes over the surfaces that have been beveled to receive the repair weld metal. Screw steel studs into the threaded holes, leaving 3/16” (5 mm) to ¼” (6 mm)of the stud above the surface. Using the methods discussed above, weld the studs in place and cover the entire surface of the break with weld deposit. Once a good weld deposit is made, the two sides of the crack can be welded together.

Understanding Cast Irons

The term "**cast iron**" designates an entire family of metals with a wide variety of properties. It is a generic term like steel which also designates a family of metals. Steels and cast irons are both primarily iron with carbon (C) as the main alloying element. Steels contain less than 2% and usually less than 1% C, while all cast irons contain more than 2% C. About 2% is the maximum C content at which iron can solidify as a single phase alloy with all of the C in solution in austenite. Thus, the cast irons by definition solidify as heterogeneous alloys and always have more than one constituent in their microstructure.

In addition to C, cast irons also must contain appreciable silicon (Si), usually from 1–3%, and thus they are actually iron-carbon-silicon alloys. The high C content and the Si in cast irons make them excellent casting alloys. Their melting temperatures are appreciably lower than for steel. Molten iron is more fluid than molten steel and less reactive with molding materials. Formation of lower density graphite in the iron during solidification reduces the change in volume of the metal from liquid to solid and makes production of more complex castings possible. Cast irons, however, do not have sufficient ductility to be rolled or forged.

The various types of cast iron cannot be designated by chemical composition because of similarities between the types. Table 1 lists typical composition ranges for the most frequently determined elements in the five generic types of cast iron.

Table 1. Range of Compositions for Typical Unalloyed Cast Irons

Percent (%)					
Type of Iron	**Carbon**	**Silicon**	**Manganese**	**Sulfur**	**Phosphorus**
Gray	2.5-4.0	1.0-3.0	0.2-1.0	0.02-0.25	0.02-1.0
Ductile	3.0-4.0	1.8-2.8	0.1-1.0	0.01-0.03	0.01-0.1
Compacted Graphite	2.5-4.0	1.0-3.0	0.2-1.0	0.01-0.03	0.01-0.1
Malleable (Cast White)	2. -2.9	0.9-1.9	0.15-1.2	0.02-0.2	0.02-0.2
White	1.8-3.6	0.5-1.9	0.25-0.8	0.06-0.2	0.06-0.2

There is a sixth classification for commercial purposes—the high-alloy irons. These have a wide range in base composition and also contain major quantities of other elements.

The presence of certain minor elements also is vital to the successful production of each type of iron. For example, nucleating agents, called inoculants, are used in the production of gray iron to control the graphite type and size. Trace amounts of bismuth and tellurium are used in the production of malleable iron, and the presence of a few hundredths of a percent magnesium (Mg) causes the formation of the spheroidal graphite in ductile iron.

In addition, the composition of an iron must be adjusted to suit particular castings. Small castings and large castings of the same grade of iron cannot be made from the same composition of metal. For this reason, most iron castings are purchased on the basis of mechanical properties rather than composition. The common exception is for castings that require special properties such as corrosion resistance or elevated temperature strength.

The various types of cast iron can be classified by their microstructure. This classification is based on the form and shape in which the major portion of the C occurs in the iron. This system provides for five basic types: gray iron, ductile iron, malleable iron, compacted graphite iron (CGI) and white iron. Each of these types may be moderately alloyed or heat treated without changing its basic classification. The high-alloy irons, generally containing over 3% of added alloy, also can be individually classified as gray or ductile iron or white, but the high-alloy irons are classified commercially as a separate group.

Understanding Cast Irons - Gray Iron

When the composition of the molten iron and its cooling rate are appropriate, the C in the iron separates during solidification and forms separate graphite flakes that are interconnected within each eutectic cell. The graphite grows edgewise into the liquid and forms the characteristic flake shape. When gray iron is broken, most of the fracture occurs along the graphite, thereby accounting for the characteristic gray color of the fractured surface. Because the large majority of the iron castings produced are of gray iron, the generic term, cast iron, is often improperly used to mean gray iron specifically.

The properties of gray iron are influenced by the size, amount and distribution of the graphite flakes, and by the relative hardness of the matrix metal around the graphite. These factors are controlled mainly by the C and Si contents of the metal and the cooling rate of the casting. Slower cooling and higher C and Si contents tend to produce more and larger graphite flakes, a softer matrix structure and lower strength. The flake graphite provides gray iron with unique properties such as excellent machinability at hardness levels that produce superior wear-resisting characteristics, the ability to resist galling and excellent vibration damping.

The amount of graphite present, as well as its size and distribution, are important to the properties of the iron. Whenever possible, it is preferable to specify the desired properties rather than the factors that influence them.

Understanding Cast Irons - Ductile Iron

Ductile iron, also referred to as nodular iron or spheroidal graphite iron, was patented in 1948. After a decade of intensive development work in the 1950s, ductile iron had a phenomenal nine-fold increase in use as an engineering material during the 1960s, and the rapid increase in commercial application continues today.

An unusual combination of properties is obtained in ductile iron because the graphite occurs as spheroids rather than as individual flakes as in gray iron. This mode of solidification is obtained by adding a very small, but specific, amount of Mg to molten iron of a proper composition. The base iron is severely restricted in the allowable contents of certain minor elements that can interfere with the graphite spheroid formation. The added Mg reacts with the sulfur and oxygen in the molten iron and changes the way the graphite is formed. Control procedures have been developed to make the processing of ductile iron dependable.

The high C and Si content of ductile iron provide the casting process advantages, but the graphite spheroids have only a nominal influence on the mechanical properties of the metal. Ductile iron, like malleable iron, exhibits a linear stress strain relation, a considerable range of yield strengths and, as its name implies, ductility. Castings are made in a wide range of sizes with sections that can be either very thin or very thick.

The different grades are produced by controlling the matrix structure around the graphite either as-cast or by subsequent heat treatment. Only minor compositional differences exist among the regular grades, and these adjustments are made to promote the desired matrix microstructures. Alloy additions may be made to ductile iron to assist in controlling the matrix structure as-cast or to provide response to heat treatment. Special analysis ductile irons and high-alloy ductile irons provide unusual properties for special applications

WELDING OF CAST IRON

Cast iron is an extremely versatile material, used in thousands of industrial products. It is hard, wear-resistant, and relatively inexpensive. Like steel, it is available in many different grades and compositions. While we usually think of cast iron as being **brittle** (having low ductility), this is not true of all cast irons, as we shall see shortly. Cast iron, like steel, is an iron-carbon alloy. In composition and structure, and in some of its properties, it is quite different from steel. While many grades of cast iron can be welded successfully, not all cast iron is weldable, and welding of any cast iron presents problems not usually encountered in the welding of steel.

Composition and Grades of Cast Iron Cast iron is by no means pure iron. In fact, there is less iron in any grade of cast iron than there is in a low-carbon steel, which may be 98% iron. Almost every cast iron contains well over 2.0% carbon; some contain as much as 4.0%. In addition, cast iron usually contains 1.2 to 2.5% silicon, 0.5 to 0.8% manganese, and (as in steel) small percentages of sulphur and phosphorous. It is the high percentage of carbon that makes cast iron different from steel in many of its properties. In finished steel, all the carbon is combined with iron in the form of iron carbides, whether those carbides are in grains of pearlite, in grains of cementite, or in scattered small particles of carbide. In cast iron, most of the carbon is usually present in uncombined form, as graphite. (Graphite is one of the two crystalline forms of carbon; diamond is the other). The differences between the general types of cast iron most widely used arise chiefly from the *form* which the graphite assumes in the finished iron.

Gray Iron.

Of the general types of cast iron, gray iron is by far the most widely used. The term ”gray iron” was adopted originally to distinguish it, by color of the fractured metal, from **white iron***,* a form of cast iron in which all the carbon *is* combined. We’ll have more to say about white iron later. At this point, we wish to stress the point that **gray iron** is a very broad term. All gray irons contain graphite in the form of flakes. This makes the gray irons readily machinable. All gray irons have almost no ductility, again because of the flake form of the graphite, which causes the metal to break before any appreciable amount of permanent elongation has occurred. However, not all gray irons are equally strong, or equally hard. As in steel, tensile strength and hardness are closely related. In gray irons, tensile strength ranges from about 14 MPa (20,000 psi) to more than 35 MPa (50,000 psi). The hardness of the strongest grades is double that of the weakest grades. All gray irons have high compressive strength – three to four times their tensile strength. While all gray cast irons contain free carbon (graphite) in flake form, they also contain combined carbon (iron carbide) in almost every case. This combined carbon is often present in pearlite grains, such as found in most carbon steels. It may also be found as cementite or martensite. The composition of the cast iron, the rate at which it cooled after casting, and heat treatment after casting all have a bearing on the structure. Small amounts of alloying elements are used in the strongest gray irons; they tend to prevent the formation of pearlite. While the hardness and strength of steel almost always increase as carbon content rises, in the case of gray cast iron the strongest, hardest grades have less carbon than some of the lower-strength, less expensive grades. Gray iron is usually cast in sand molds, and allowed to cool normally in the mold.

Heat treatment after casting is not always necessary, but is frequently employed, either to increase or to decrease hardness. Almost all gasoline and diesel engine blocks are gray iron castings. Whenever industry desires an intricate form which can be machined to close tolerances, and must withstand abrasive wear, gray iron gets consideration.

Only when it is essential that the finished item have some ductility and good shock resistance is some other material – such as nodular cast iron or cast steel, both more expensive – likely to be substituted. White iron, mentioned above, is about the same as gray iron in composition, but has been cooled rapidly so that graphite does not have time to form, and all the carbon winds up in the combined form, as pearlite, cementite, or martensite. Many white iron castings are subsequently converted to malleable iron, which we shall take up next. However, some gray iron castings are made with white iron wearing surfaces, since white iron is much harder than gray iron, although extremely brittle. This is accomplished by inserting metal or graphite chill blocks at appropriate places in the mold. The molten metal that solidifies against those chill blocks cools so rapidly that white iron surfaces are created. Plowshares, railroad car wheels, and various types of dies are often made with such chilled white iron surfaces.

Nodular Iron.

Nodular cast iron, sometimes called **ductile iron**, has many of the properties of malleable iron.

Nodular cast iron is made by **inoculating** the molten metal, just before casting, with a small amount of **magnesium** or **cerium**. This causes the free carbon in the finished casting to appear as rounded nodules of graphite, rather than as flakes. Each nodule is surrounded by a zone of ferrite (carbon-free iron) with the balance of the metal usually in the form of pearlite. Nodular iron has less ductility than malleable iron (which can have almost as much ductility as mild steel) but far more than ordinary gray iron, which has virtually none. It usually has high strength; in fact, the yield strength of a nodular iron is almost always greater than that of mild carbon steel. All nodular irons have one property which clearly sets them apart from most gray irons; they have a high **modulus of elasticity**. In simpler terms, they have excellent **stiffness**, a property much desired in parts like propeller shafts or forming rolls. Where most gray irons are much more elastic (less stiff) than steel, nodular cast iron is nearly as stiff as cast steel. Like malleable iron, nodular iron cannot be fusion welded and retain all of its original properties. This is especially true of nodular iron castings which have been heat-treated after casting. A fusion weld made in nodular iron may not cause loss of tensile strength, but will almost always reduce the shock resistance of the part. Braze welding can be used on nodular iron if some sacrifice of tensile strength can be tolerated.

Alloy Cast

Irons. Alloying ingredients – chromium, nickel, molybdenum, and, occasionally copper or aluminum – are added to cast iron for three principal purposes: to increase wear resistance, to increase resistance to scaling in high-temperature service, and to increase corrosion resistance. In some alloy cast irons, the silicon level is also increased substantially. Some of the extra-hard, abrasion-resistant alloy irons are *white* irons; they appear almost white when fractured because they contain virtually no free carbon. Others may have the general appearance of gray cast iron. The range of compositions is so great that no general statement about the weldability of alloy cast iron can be made. So far as the oxy-acetylene process is concerned, fusion welding is not recommended; braze welding will not permit retention of all the properties for which the alloy iron was originally specified. Gray cast iron can usually be welded without loss of essential properties. For fusion welding, preheating of the casting is absolutely essential. Since a higher level of preheat is required for oxy-acetylene welding then for arc welding, arc welding is likely to be chosen where fusion welding is essential (as it is whenever good color match is desired). For many repair jobs, however, oxy-acetylene braze welding is the ideal method. Much less preheating is required; in many cases, preheating can be done with the torch. If the work is properly done, the braze-welded joint will have strength equal to that of the base metal, and excellent machinability. Welding of gray iron castings which have chilled white iron surfaces is seldom attempted, since the desirable properties of white iron will always be affected by welding temperatures. Welding of white iron generally is limited to malleable iron foundries, where castings may be reclaimed by welding before conversion to malleable iron takes place.

Malleable Iron.

The chemical composition of malleable cast iron is much the same as that of a typical gray iron, but its properties are much different. It is tough; it can resist shock; it has ductility approaching that of mild steel. How is such a remarkable change achieved? By cooling the original casting so rapidly that white cast iron, with no free carbon, is formed; then heating the casting to about 800^0C and holding it at that temperature for several days. Under those conditions, virtually all the carbon is released from the iron carbide to form fine rounded particles of graphite (sometimes called **temper carbon**) scattered among grains of ferrite. Malleable iron has good wear resistance, and is widely used for parts where the toughness of steel is required, and the economy of casting (instead of forming or machining) will result in lower cost. However, malleable iron is substantially more expensive to make than gray iron, and is usually selected only where its toughness and ductility are essential. Malleable iron cannot be successfully fusion welded and retain its unique properties; to put it another way, you can weld malleable iron as easily as you can weld gray iron, but in the act of welding you will convert some of the malleable iron casting into a gray iron casting. Seldom will that yield a satisfactory result. However, malleable iron castings can usually be braze welded successfully. You may wonder how to tell a malleable iron casting from a gray iron casting. There's one almost infallible method: use a high-speed grinder to make a spark test. The difference between the spark streams produced by gray iron and malleable iron is quite pronounced. Spark testing is covered in the Appendix.

The Importance of Preheating

For Fusion Welding. If you are called on to weld cast iron, the material to be welded will almost always be gray iron. Gray iron is brittle; it has virtually no ductility. If the forces of expansion or contraction, as generated during the welding operation or in cooling after welding, are concentrated in one area of the casting, cracking of the casting, or of the cooling weld, will almost certainly occur. Even at elevated temperatures, gray cast iron has little"give"; it will break, rather than stretch, when the force of expansion or contraction exceeds its yield strength. Therefore, whenever a casting must be fusion welded, it is usually necessary to preheat the entire casting, slowly and evenly, before welding is started, and then allows the casting to cool slowly after welding has been completed. This will permit all sections of the casting to expand and contract at a reasonably uniform rate. The temperature to which a casting must be preheated depends somewhat upon the welding process to be used. Oxy-acetylene fusion welding puts more heat into the casting than does arc welding, and therefore requires a higher level of preheat, usually to about 600^0C (1100^0F). The preheat temperature level is also somewhat dependent upon the size and form of the casting. Rather simple castings, without major variations in section thickness, usually require less preheat than complex castings. If a suitable furnace is not available for preheating a casting, one can be improvised out of fire brick, as suggested in Chapter 13. If the casting is preheated in a furnace, and then withdrawn for welding, it is essential that as much of the casting as possible be insulated during the welding operation, to hold the preheat as well as protect the welder. Asbestos paper will be found almost indispensable during the fusion welding of cast iron.

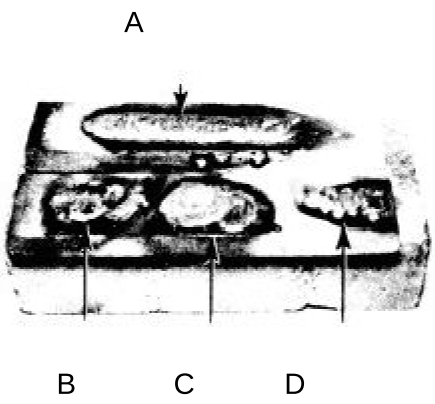
For Braze Welding.

When a casting is to be braze welded, some preheating is usually required, but the level of preheat temperature can be much lower, and many jobs can be done without preheating the entire casting. In braze welding; there is no danger of weld cracking. Bronze weld metal has extremely high ductility, and is capable of absorbing any contraction stresses to which it may be subjected. Because the temperature of the casting itself, even in the metal immediately adjacent to the weld metal, need never exceed 900^0C, changes in the physical properties of the casting metal will seldom occur. That is why malleable iron castings can often be braze welded.However, even the heat input involved in braze welding may be enough to cause cracking of a gray iron casting (or leave the casting with residual stresses which might cause cracking at a later time) if some preheating is not performed. If preheating of the complete casting is feasible, it should be done, although the temperature need not be raised to more than $300\text{-}400^0$C. In most cases, thorough preheating of the metal adjacent to the weld zone, using the welding torch, will be sufficient.

Braze Welding Practice

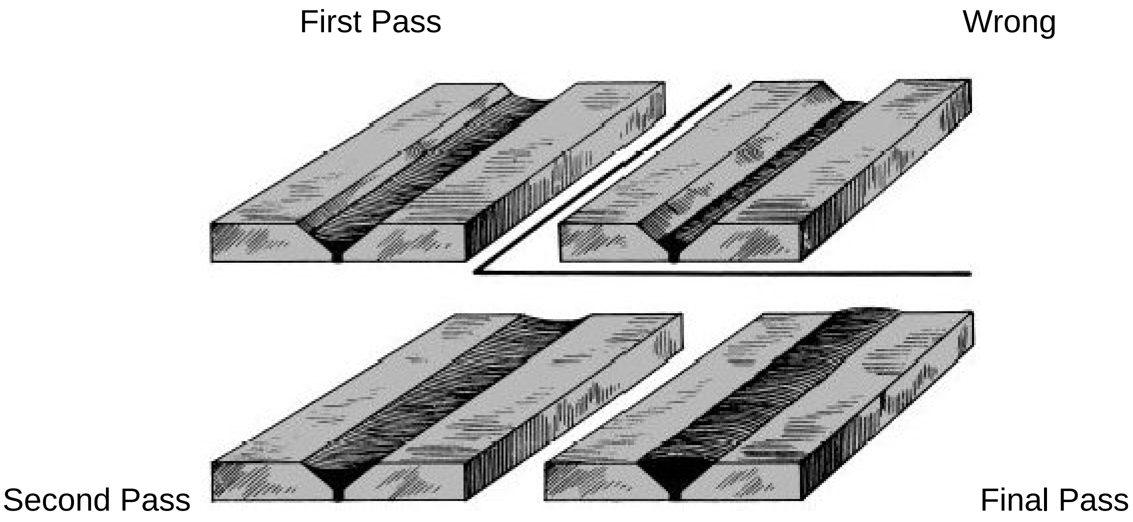
If you have already braze welded pieces of steel plate, as suggested in the preceding chapter, the braze welding of cast iron should present no new problems. If possible, get some coupons of cast iron, about 13mm (1/2 in.) thick, which some foundries cast especially for welding practice. If not, locate some pieces of a broken casting and use them. Prepare the edges of the joint carefully. The included angle of the weld vee should be a full 90^0, and the edges must be thoroughly cleaned. Grinding, followed by filing, is recommended. (The file will remove any loose particles left by the grinding wheel, as well as any graphite flakes which might interfere with proper tinning of the metal.) Be sure to remove all traces of grease or paint from the metal surface immediately adjacent to the weld vee. For braze welding cast iron about 13mm (1/2 in.) thick, we suggest that you use a welding tip which consumes 15 cfh of acetylene, and a slightly oxidizing flame. (To secure that, adjust the flame carefully to neutral, and then throttle the acetylene flow enough to shorten the flame inner cone slightly.) You must also have a good braze welding flux, such as OXWELD BRAZO flux or OXWELD Cast Iron Brazing Flux. (The latter is more expensive, but contains bits of bronze”spelter” which help you to determine when the casting has reached the proper temperature for tinning.) Since tack welding will seldom be called for in actual repair work on castings, we suggest that you merely space the two pieces of cast iron so that there is a gap of about 1.6 mm (1/16 in.) at the starting point of the weld, and a gap of 5 to 6 mm (3/16 to 1/4 in.) at the finishing point. If you are using a welding table with a cast iron top, be sure to raise the finishing end of the joint a bit above the table, lest you actually weld the specimens to the table. If the cast iron coupons or the pieces of casting are at least 13 mm (1/2 in.) thick, we suggest that you plan to make your weld in three passes.

After lighting the torch, pass the flame back and forth along the entire length of the weld zone several times,holding the tip of the inner cone at least 13 mm (1/2 in.) away from the metal surface. Then concentrate the flame in an area about 8 cm (3 in.) in diameter at the starting end. The cast iron will be ready for tinning just as it starts to turn a very dull red color. (To spot this point in a brightly lighted room, through the dark lenses of welding goggles, isn’t always easy. It will take practice to acquire the knack of instantly recognizing that first glow.) You should have heated the end of the welding rod and dipped it in flux while you were preheating the metal. Now melt just a little of the bronze onto the surface of the vee. If it balls up and tends to roll down the surface, the metal isn’t hot enough. Withdraw the rod and continue heating for a few seconds. Dip the rod in flux again and make a fresh start. If the molten rod tends to bubble up on the cast iron surface, and run around like drops of water on a fairly hot stove top, the cast iron is too hot. You must withdraw the flame and let the iron cool down a bit before trying to deposit more filler metal. Good and poor deposits of bronze on cast iron coupons. At A, results were first- class. At B, surface of cast iron had not been ground, so tinning was uneven. At C, too much heat was used, while at D too little heat was used.



Good and poor deposits of bronze on cast iron coupons. At A, results were first- class. At B, surface of cast iron had not been ground, so tinning was uneven. At C, too much heat was used, while at D too little heat was used.

Once proper tinning action has been started, continuing the first pass is largely a matter of maintaining the tinning action and melting in the right amount of bronze. Always try to get tinning action which extends a good halfway up each side of the vee, but deposit no more bronze than necessary to achieve a **concave** weld contour. If you do not tin the sides of the vee enough, and then try to melt in too much metal, you'll arrive at a **convex** weld metal surface and find it very hard to make the second pass without running molten bronze onto parts of the iron surface that have not been properly tinned. On the second pass, tinning action should be carried to the top of each side of the vee, and enough bronze melted to secure another concave surface, not a convex surface. Be sure that the additional filler metal added in this pass in is completely fused to the bronze deposited in the first pass. If there is not complete fusion between the first- pass bronze and the second- pass bronze, what appears to be a good weld may actually be less than full strength. In making the third pass, try to achieve a good ripple and a good shape for the top surface of the weld. Carry the weld just a bit past the top of the vee on each side, making sure that the cast iron surfaces tin before the puddle passes the top of the vee.



Sketches to illustrate proper contours for successive passes with bronze rod. Except when making the final pass, try to achieve a concave surface on the weld metal.

Testing a Practice Weld.

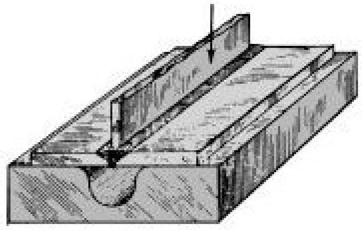
If your first weld looks good, and the underside of the weld shows complete penetration

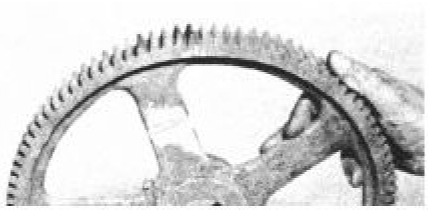
Without too many unsightly protrusions, you should find a way to test it. The methods suggested for testing welds in steel sheet and plate are not really suitable for braze welds. For one thing, you can't cut out a coupon with your cutting torch or attachment. More important, any test which involves hammering the specimen is likely to cause the cast iron to fracture, even if the weld is less than perfect. For a very rough test (if welding was done on flat pieces) you can place the specimen in a heavy vise, with the centerline of the weld parallel to the vise jaws and level with the top edge of the jaws. Then strike the specimen, above the weld line, with a heavy hammer. If you can break the specimen, and the break occurs in the cast iron, not along the weld zone, you know that the weld was at least passable. A far better method of testing, if you have the means for doing it, is illustrated in. If a steadily increasing force is applied, the specimen will ultimately break, and if you have made a really good weld, it will break through the cast iron, with no evidence of bronze on either side of the fracture. If one surface of the fracture shows bits of bronze, indicating that the weld broke through the bronze-cast iron bond at that point, it indicates that you did not attain complete tinning of the cast iron during the welding operation. On your first weld, lack of proper fusion at the bottom of the vee will usually be the result of overheating the cast iron, rather than under heating it.

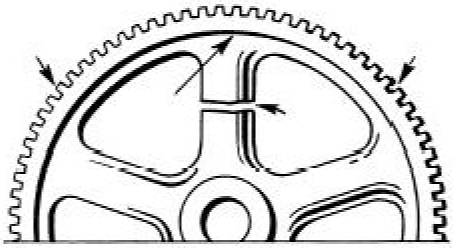
Tips on Braze Welding.

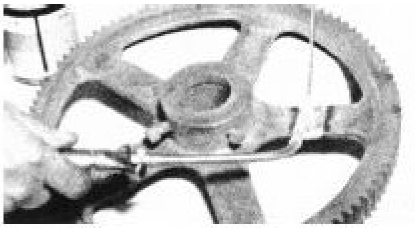
A cast iron surface that has been exposed to fire may prove hard to tin, even after thorough mechanical cleaning. Spreading a strong oxidizing agent, such as powdered potassium chlorate, on the well- heated surface, just ahead of the weld puddle, will often help. The chlorate will foam; once foaming starts, tinning will proceed normally. A cast iron surface which has been exposed to oil and grease for a long period will actually absorb some of that material, and normal cleaning methods will not remove it. The answer to that problem is to heat the surface bright red before any attempt is made to weld it. That will usually vaporize and burn the grease out. Before repairing any casting, take time to study the job in advance, and decide how to clamp it or support it so that welding can be done most easily. If there are a series of cracks, try to plan the welding sequence so that welding one crack isn't likely to create expansion forces which will enlarge another crack.

A method for testing a braze weld in cast iron is illustrated by this sketch. A steady force should be applied in the vertical direction, as indicated by the arrow.









Three steps in the repair by braze welding of a cracked spoke in a cast iron gear. First, the crack should be beveled on each side, leaving at least 1/16 in. of metal in the middle, between the two vees. Then the rim of the gear should be heated strongly, as illustrated by the sketch in the center. This will cause the rim to expand and will open up the crack somewhat. Finally, without delay, the weld area should be preheated with the torch and bronze deposited, first on one side of the spoke, then on the other.

No matter how you preheated a casting for braze welding; always do everything possible to permit slow, even cooling. Frequently it will help to play the torch flame gently over the surface of the metal for a considerable area surrounding the weld, to bring the piece as a whole to a more even heat level. Whenever possible, cover the part with asbestos paper, or, if it is small, bury it in dry slaked lime. Always protect the part from drafts. Heat here Heat here Crack enlarges Rim expands outward Heat causes rim to bow outward, opening crack

Fusion Welding

The general rule for the oxy-acetylene fusion welding of gray iron castings is that the entire casting be preheated in a furnace to dull red heat (about 800^{0}C), that the actual welding be done under conditions which will allow the retention of most of the preheat, and that the casting be allowed to cool slowly after the welding. Whenever possible, the casting should be reheated to a uniform temperature of about 750-800^{0}C after welding, and cooling to room temperature should require at least one full day. When these conditions can be met, the results should be good. In some cases, depending on the size of the casting, and the thickness of its various sections, fusion welding can be done successfully with only local preheating to a dull red color. However, it would be unwise to attempt fusion welding without full preheat unless you have had considerable experience in the fusion welding of cast iron, and feel thoroughly competent to assess the effects of expansion and contraction on the whole casting. Few oxy- acetylene welders get the chance to acquire that kind of experience. You do not, however, require previous experience, or a preheating furnace, to acquire the basic skills involved in making a fusion weld. The welding action is quite different from that with which you are familiar (if you have previously welded only steel, or braze welded cast iron) so we suggest that you make a few practice welds in small pieces of cast iron.

Materials Required for Practice Welds.

You will need two or more pieces of 13mm (1/2-in.) cast iron, about 3 by 6 in. in area, with edges beveled to an angle of 45 degrees (the same as suggested for braze welding practice). Torch tip size should be the same as that you used for braze welding 13-mm (1/2-in.) cast iron. Filler metal should be cast iron rod especially formulated for welding (either gray iron or nodular iron). A flux designed specifically for fusion welding of cast iron is required, such as OXWELD Ferro Flux. (Do not attempt to use a brazing flux. It will not serve this purpose.)

Practice.

The beveled edges of the pieces should be filed thoroughly. If the bottom of the beveled edge is sharp, it should be filed to give you square edges, at least 2 mm (3/32 in.) deep, at the root of the weld. The pieces should be positioned so that there is a gap of about 1.6 mm (1/16 in.) at the weld starting point and about 5 mm (3/16 in.) at the finishing point. For fusion welding of cast iron, a neutral flame should be used, not the slightly oxidizing flame suggested for braze welding. First preheat the entire weld zone thoroughly with the torch flame. Try to reach dull red heat along the entire length of the welding vee. Then heat the bottom of the vee, at the starting end, until the actual melting has started. Angle the torch flame as you did in steel welding; keep the inner cone at least 3 mm (1/8 in.) from the metal, however. When a small puddle has formed at the base of the vee, move the flame from side to side to melt down the sides of the vee gradually. Only after you have a fair-sized puddle should the rod, which has been preheated in the flame and dipped in the flux until it is well-coated, be introduced into the puddle. From this point on, your aim must be to keep the rod in the puddle, and to allow the heat from the puddle, not the flame itself, to do the actual melting of filler metal. Try to avoid withdrawing the rod from the puddle except when more flux is needed on the rod. Never hold the rod above the puddle and allow it to melt into the puddle drop by drop. Direct the flame against the puddle, and against the sides of the vee. You must make the weld in one pass, not two or three. Therefore, you must not allow the puddle to advance too rapidly along the root of the vee. Keep the rod in the puddle, fill the vee completely for a length of perhaps one inch, then redirect the flame to melt the lower edges of the vee and allow the puddle to advance. You will find the puddle more fluid than the puddle you handled in steel welding, since cast iron does not have the fairly wide ”mushy” range which make steel welding quite easy. Therefore, extra care to avoid letting the puddle run ahead and roll onto metal which has not yet reached fusion temperature is required. While making the weld, you may see gas bubbles or white specks in the puddle. During your first weld, we suggest that you ignore them. Thereafter, you must take pains to work them out as you go along, by adding flux to the rod, and by playing the flame around the specks until they float to the very top of the puddle. Once they float to the top, skim them off with the tip of the welding rod, and tap the end of the rod gently on the welding table to dislodge them. Removal of such visible particles (usually dirt, or impurities in the base metal) is essential if a full-strength weld is to be secured.

Once the weld has been completed, reheat the entire weld with the torch until it glows faintly. Then place the welded specimen between sheets of asbestos paper to allow it to cool as slowly as possible. After the weld has cooled completely, wire brush the surface of the weld on both sides, and examine it carefully. Note particularly the appearance of the underside. If thorough fusion between the bottom edges of the vee has not been obtained, the defect can be clearly seen. The bottom of a good weld will show little round beads of weld metal protruding through. Test your weld by clamping the specimen in a large vise, with the centerline of the weld flush with the tip of the jaws. Strike the upper part of the specimen with a heavy hammer until the part breaks. If you have made a good weld, the break will probably occur in the base metal, not in the weld. If it breaks through the weld, examine the fracture carefully for inclusions, gaps, or blowholes. If the break occurs in the base metal, remove the specimen from the vise, nick it with a hacksaw, on both sides of the weld zone, then return it to the vise and break it across the weld. Examine the fractured weld metal carefully to see whether it appears sound, with no slag or oxide inclusions or blowholes.

Practical Hints

If you are preheating a casting with the torch, or in an improvised furnace, watch carefully to make sure that you do not overheat any part of the casting. It should never get more than dull red. If it gets too hot, it may warp from its own weight, and become completely unrepairable. Try to keep the thinner sections farthest from the heat source if an improvised preheating furnace is being used. Just as the foundry man must rely on experience, and the use of correct foundry practices, to feel quite sure that a finished casting with no visible defects is sound, so a welder must follow correct procedures, with emphasis on proper preheating and cooling, if he is to feel confident that a good-looking fusion weld in cast iron will stand up in service. Of course, he can leak- test a weld in a water jacket. A weld which must be leak tight, but cannot be tested under pressure in the repair shop, can be checked rather well by applying kerosene to one side of the weld. Kerosene will work its way rapidly through even a slightly porous weld. But such tests cannot be conclusive as to the overall soundness of the weld, and the final condition of the repaired casting.

EXPANSION & CONTRACTION

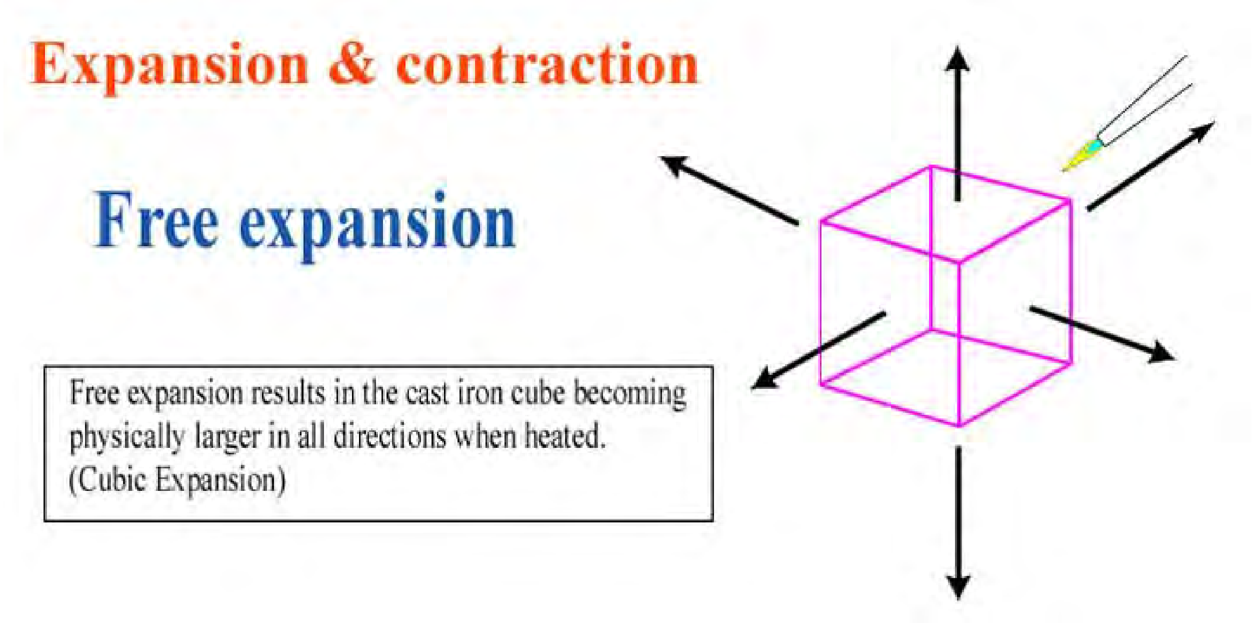
What happens to you when you break a law, even if you don't know about that particular law? Usually something you don't like, right? Well, cast iron will obey the laws of physics, even if you don't know them. So, it makes a lot of sense to learn the laws before something happens that you don't like. Right?

First, let's talk about expansion and contraction. This is extremely important and very easy. Understanding these principles can prevent you from having welding catastrophes.

When cast iron (and other metals)are heated, they expand.

- Expansion is cubic (or equal in all directions) **unless** the heated metal is contained.
- When cast iron (and other metals) cool, they contract.
- Contraction is cubic (or equal in all directions) **unless** the cooling metal is contained.

Free expansion results in the cast iron cube becoming physically larger in all directions when heated.

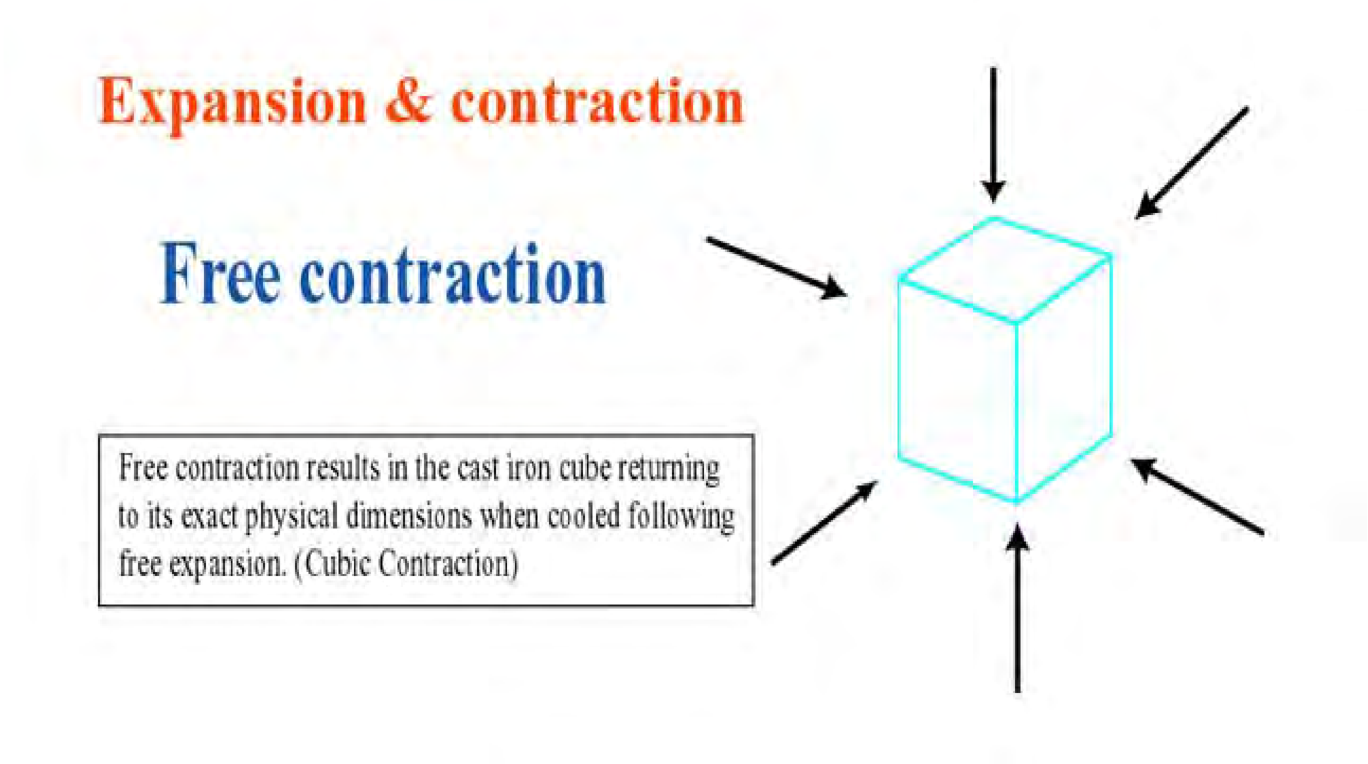


Expansion & contraction

Free expansion

Free expansion results in the cast iron cube becoming physically larger in all directions when heated. (Cubic Expansion)

Free contraction results in the cast iron cube returning to its exact physical dimensions when cooled following free expansion.



Expansion & contraction

Free contraction

Free contraction results in the cast iron cube returning to its exact physical dimensions when cooled following free expansion. (Cubic Contraction)

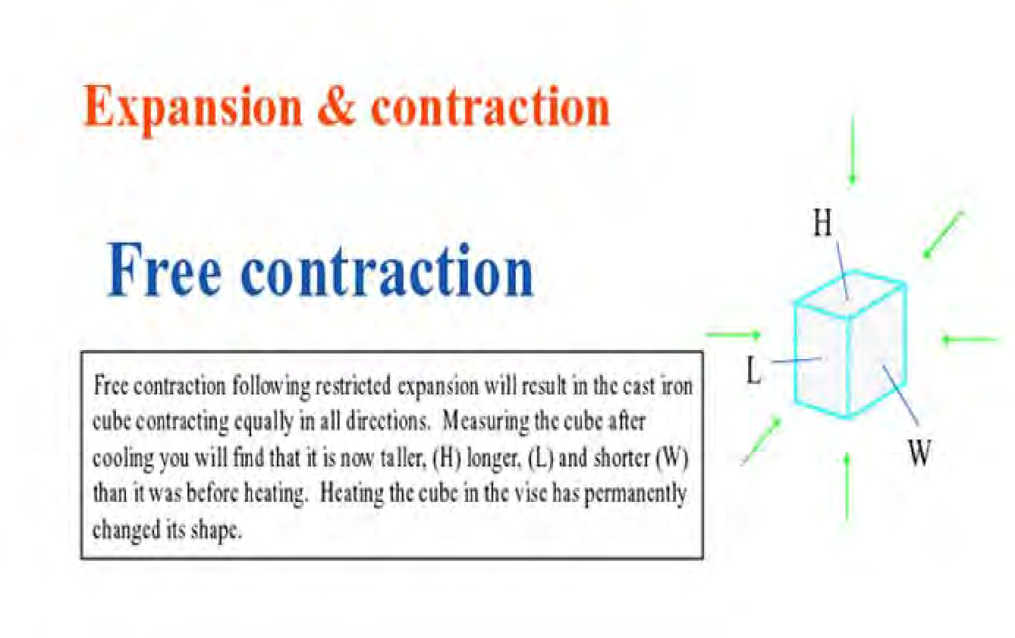
Restricted expansion occurs when cast iron is confined on two or more sides when heated. The cube will only be able to expand up and down plus side to side, not against the vise. Heating the cube while restricted by the vise will change its physical dimensions permanently.

Expansion & contraction

Restricted expansion

Restricted expansion occurs when cast iron is confined on two or more sides when heated. The cube will only be able to expand up and down plus side to side, not against the vise. Heating the cube while restricted by the vise will change its physical diminsions permanently.

Free contraction following restricted expansion will result in the cast iron cube contracting equally in all directions. Measuring the cube after cooling you will find that it is now taller, longer, and shorter than it was before heating. Heating the cube in the vise has permanently changed its shape.

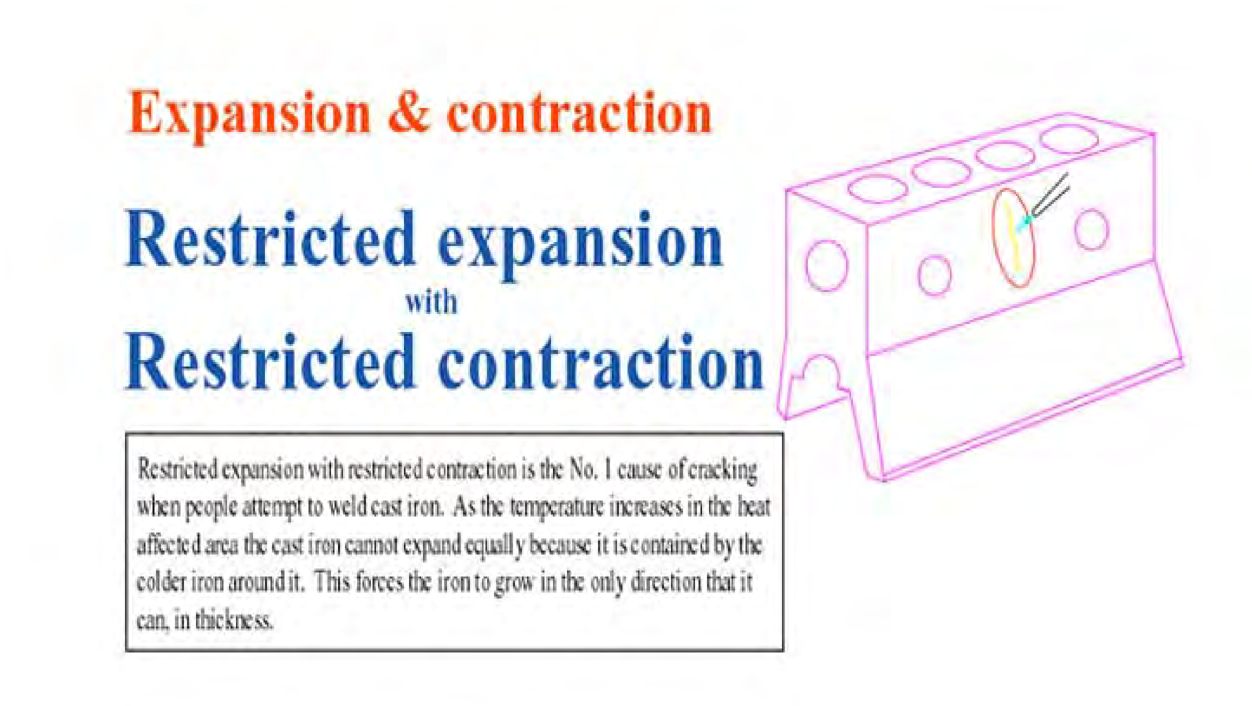


Expansion & contraction

Free contraction

Free contraction following restricted expansion will result in the cast iron cube contracting equally in all directions. Measuring the cube after cooling you will find that it is now taller, (H) longer, (L) and shorter (W) than it was before heating. Heating the cube in the vise has permanently changed its shape.

Restricted expansion with restricted contraction is the number one cause of cracking when people attempt to weld cast iron. As the temperature increases in the heat-affected area, the cast iron cannot expand equally because it is contained by the colder iron around it. This forces the iron to grow in the only direction that it can: thickness.

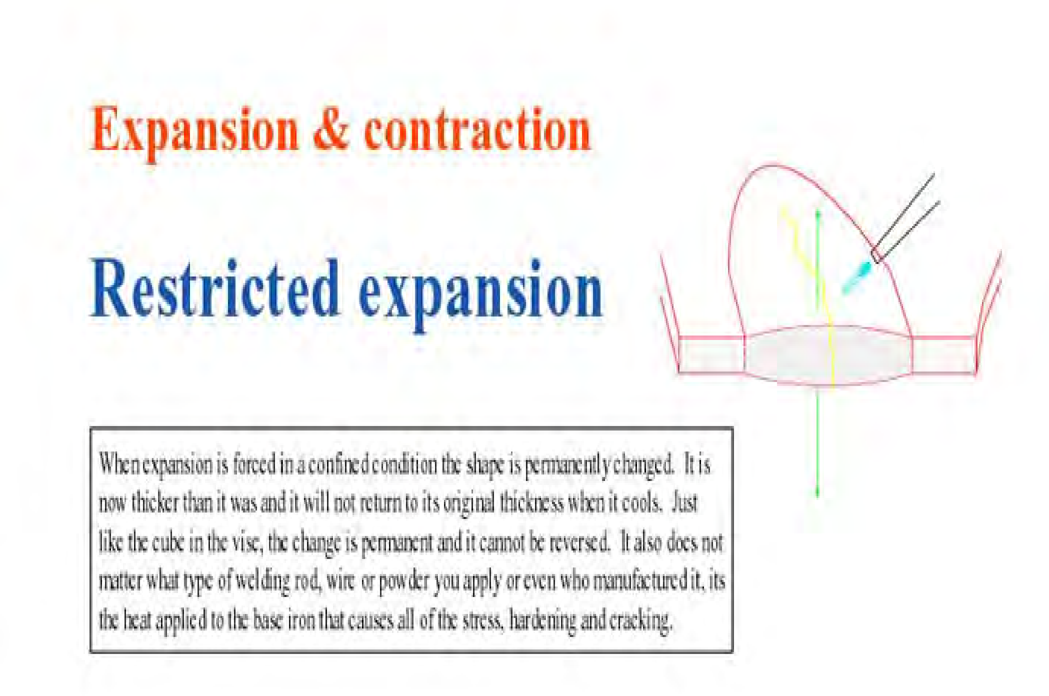


Expansion & contraction

Restricted expansion
with
Restricted contraction

Restricted expansion with restricted contraction is the No. 1 cause of cracking when people attempt to weld cast iron. As the temperature increases in the heat affected area the cast iron cannot expand equally because it is contained by the colder iron around it. This forces the iron to grow in the only direction that it can, in thickness.

When expansion is forced in a confined condition the shape is permanently changed. It is now thicker than it was and it will not return to its original thickness when it cools. Just like the cube in the vise, the change is permanent and it cannot be reversed. It also does not matter what type of welding rod, wire or powder you apply, or even who manufactured it. It's the heat applied to the base iron that causes all of the stress, hardening and cracking.



Expansion & contraction

Restricted expansion

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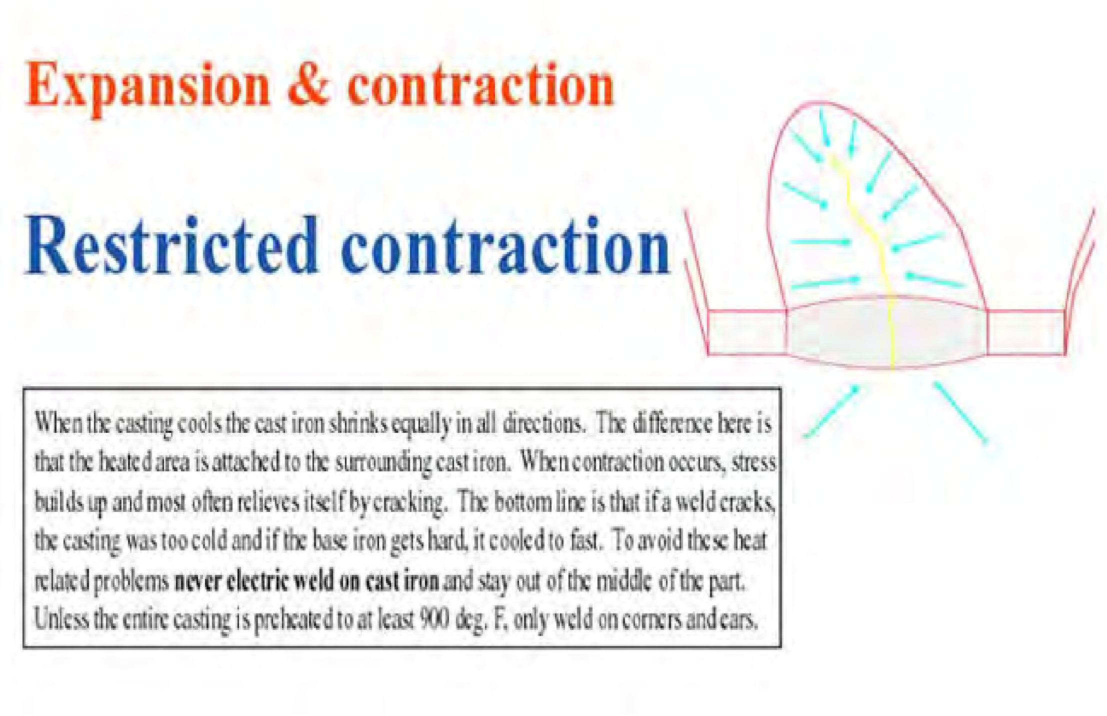
When the casting cools, the cast iron shrinks equally in all directions. The difference here is that the heated area is attached to the surrounding cast iron. When contraction occurs, stress builds up and most often relieves itself by cracking. The bottom line is: if a weld cracks, the casting was too cold; if the base iron gets hard, it cooled too fast. To avoid these heat related problems never electric weld on cast iron and stay out of the middle of the parts. Unless the entire casting is preheated to at least 900°F, only weld on corners and ears.



Expansion & contraction

Restricted contraction

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PREHEATING & WELDING PROCEDURES

Here are some very specific preheating and welding procedures to help you perform cast iron repairs that are predictable and reliable.

Brazing

The casting must be preheated to at least 900ºF before you begin increasing the temperature in the area you want to braze. The bronze rod will melt at around 1725ºF. A good bonding temperature is 1800ºF. The casting should be positioned so that you are brazing on an incline of at least 30 degrees. Avoid "in position" or flat brazing as this causes pin holes, cold laps, and burnt edges.

Brazing uphill allows you to fill the vee from bottom to top in one pass. Small, thin steps allow you to move quickly and keep the area ahead of the puddle tinned.

Be sure to post heat to normalize the casting at 900ºF. Slow cool the part over 24 hours.

Many people believe bronze to be an inferior metal to use on cast iron. Actually, bronze matches cast iron closely in hardness and metal to metal wear resistance.

Gray cast iron has a maximum tensile strength of 40,000 PSI. And ductile iron (or nodular) can reach 75,000 PSI tensile strength. Common bare bronze is 70,000 PSi tensile strength.

Fusion welding

Fusion welding is a skill that can take years to master. It requires actual melting and puddling of base metal as the filler material is added. Fusion welding is used primarily on dense castings that can be machined after the welding is done. (Cylinder heads are excellent subjects for fusion welding but engine blocks are not.) A 1300ºF to 1500ºF preheat is required. For a heating source, use natural gas or diesel fuel. Do not use propane. Use oxy-acetylene gas and bare cast iron rod for the fusion welding process.

Heat the part and maintain it at bright red during the entire welding procedure. Cast iron melts at approximately 2300ºF. A post heat of 1300ºF to 1500ºF for 15 minutes is needed. Slow cool the part over 24 hours.

Powder welding

Preheat the casting to 900ºF, apply a light coat of powder to protect the surface from ferrite oxide deposits and then continue the preheat to at least 1300ºF. During the build-up process, the weld affected area can reach 1800ºF in the area the capillary bond process takes place. Without high temperature preheat, powder welding should be restricted to corners, ears and ends.

Corners, ears, and ends

It is impossible to create stress on corners, ears and ends. A good illustration of this is if you welded two pieces of welding rod together. The ends have nothing to expand against, therefore there is no confinement. After joining the two pieces together, the heated area can contract and shrink without creating stress. If you *must* use a nickel rod on cast iron, use it only on corners, ears and ends. Preheat the area with a torch to a dull red, arc weld it and immediately post heat with the same torch.

It is best to use two people, one to preheat and post heat and the other to weld. Timing is critical. You will also need to use less amps when the iron is preheated. Your best bet is to learn how to braze and forget the arc welder. (This also applies to tig and mig welding.)

Electric arc welding

This is the poorest of all choices for welding cast iron. It would be nice if it would work, but it causes so many problems it should be avoided if at all possible. The heat potential is great and the process causes the heat to be too localized. Thin sections heat faster and cool quicker than thick sections. If a section of the casting is heated too quickly, the surrounding area does not have ample time to absorb enough heat to allow the casting to have a uniform temperature. This causes restricted expansion and contraction. It occurs when the weld affected area is contained by cooler iron.

This will always result in some stress. Often it is enough stress to cause additional cracking. There is no such thing as cold arc welding; cast iron melts at 2300ºF. No professional industrial cast iron welder would ever arc weld on a casting heated to less than 1000ºF.

Nickel rod

In our shop, we can tell no difference between one manufacturer's rod and another. There are repairs where we must use nickel rod, such as on compressors in the oil field. In these cases, H_2S gas is present and bronze is not acceptable. We will preheat to 1200ºF before welding, followed by a long post heat to a uniform 1200ºF before a 24 hour cool down. The critical part of the cool down is from 1800ºF to 1200ºF.

Recap

Let's add together the things you have learned about expansion and contraction along with temperature control and review the ways to prevent stress from building up in your welded cast iron parts:

- Use a high temperature preheat when welding in the center of a casting.

- Limit low temperature welding and brazing to corners, ears and ends.

- Use a proper preheat and maintain the part at the appropriate temperature during the entire welding process.

- Cool the casting very slowly in order to allow the weld affected area to stretch with the contraction of the weld.

Cutting Tip Data

IMPORTANT: Use proper type seat cutting tips for each type of torch and fuel gas. Use proper type tips for fuel gases or acetylene. See manufacture's chart for proper tip selection. Use proper tip size, pressures and flame size to avoid backfire and flashback.

CUTTING OXYGEN PRESSURE GUIDE

Type 101 etc. Victor type seat, tube mix lower psig.
Type 144 etc. Airco type seat, tip mix mid psig.
Type 6290 etc. Harris type seat, head mix upper psig.
SCFH, std. cu. ft. per hr. PSIG, pounds per square inch guage

WARNING:
Do not operate this equipment until you fully understand its safe and proper use. The safe and effective use of the equipment depends on the user fully understanding and carefully following practical time-tested safety operation instructions to prevent and avoid unnecessary painful injuries and costly property damages and losses.

Read all operating instructions carefully before using equipment. Do not light torch until all connections are leak tight. Purge out torch before lighting.

WARRANTY CLAUSE: Uniweld believes the information contained herein to be reliable. However, the technical information is given by Uniweld without charge and the user shall employ such information at his own discretion and risk. Uniweld assumes no responsillity for results or damages incurred from the use of such information in whole or in part.

	Torch and Tip Types			Oxygen		Acet./Fuel Gas		
	Victor Type Seat 2 tapper	Airco Type Seat 3 tapper	Harris Type Seat 2 flat					
Metal Thickness	1-101 3-101 5-101 GPM-N-P	144 164	6290	PSIG	SCFH	PSIG	SCFH	Speed IPM
1/8"	000	00	000	20-25	25	5	5	28-32
1/4"	00	0	00	20-25	35	5	6	25-30
3/8"	0	1	00	25-30	60	5	8	24-28
1/2"	0	1	0	30-35	65	5	10	20-24
3/4"	1	2	1	30-40	85	5	13	17-20
1"	2	2	1	35-50	140	6	16	15-20
1-1/2"	2	3	2	40-50	160	7	18	12-17
2"	3	3	3	40-55	180	9	22	12-15
2-1/2"	3	4	3	45-55	230	10	26	10-13
3"	4	5	4	45-60	280	10	30	9-12
4"	5	5	4	45-60	350	12	34	8-11
5"	5	6	4	50-65	420	12	38	7-9
6"	6	6	5	50-70	450	12	40	6-8
8"	6	6	5	55-75	600	14	44	5-6
10"	7	7	6	68-85	700	14	50	4-5
12"	8	8	6	55-95	900	14	55	3-5

Weld/Braze Tip Data

IMPORTANT: Use proper type of tip for each type torch

Weld/ Braze Tips Metal Thickness	Victor Type Seat	NUMBER Drill Size	DECIMAL Size	Harris Type Seat	NUMBER Drill Size	DECIMAL Size	Airco Type Seat	NUMBER Drill Size	DECIMAL Size	Pressure**		Acet scfh**
	Type 1, 4, 13, 17			Type 79			Type 96					
	Size			Size			Size			Oxy psi	Acet psi	
Up to 1/32"	000	75	(.021)	0	70	(.028)	00	76	(.020)	3-5	3-5	1-2
1/16"-3/64"	00	70	(.028)	1	67	(.032)	0	72	(.025)	3-5	3-5	1.5-3
1/32 5/64	0	65	(.035)	2	62	(.038)	1	68	(.031)	3-5	3-5	2-4
3/64 3/32	1	60	(.040)	3	57	(.043)	2	62	(.038)	3-5	3-5	3-6
1/16 1/8	2	56	(.0465)	4	56	(.0465)	3	56	(.0465)	3-5	3-5	5-10
1/8 3/16	3	53	(.0595)	5	55	(.052)	4	54	(.055)	4-7	3-6	8-18
3/16 1/4	4	49	(.073)	6	53	(.0595)	5	51	(.067)	5-10	4-7	10-25
1/4 1/2	5	43	(.089)	7	50	(.070)	6	48	(.076)	6-12	5-8	15-35
1/2 3/4	6	36	(.1065)	8	47	(.0785)	7	45	(.082)	7-14	6-9	25-45
3/4 1-1/4	7	30	(.1285)	9	43	(.089)	8	40	(.098)	8-16	8-10	30-60
1-1/4" - 2"	8	29	(.136)	10	40	(.098)	9	35	(.110)	10-19	9-12	35-75
2-1/2" - 3"	10	27	(.144)				10	30	(.1258)	12-24	12-15	50-100
3-1/2" - 4"	12	25	(.1495)							18-28	12-15	80-160

* The approx. Oxygen consumption ration for various gasses is as follows:
1 oxygen to 1 acetylene
2 oxygen to 1 Mapp®/Natural gas
4 oxygen to 1 propane/propylene

Gas consumption data is merely for estimating purposes. It will vary due to the material, skill of the operator and working conditions
**Use same pressures for fuel gas for brazing and one size or larger tip. Pressures are approximate for hose lenght up to 25ft, increase for longer lengths about 3 psi for every 25ft, increase working pressure 2-3 psi for check valves.

NOTE: Oxy-acetylene must be used to produce satisfactory welds in steel.

Acetylene cylinder gas withdrawal should not exceed 1/7 (15%) of cylinders contents per hour. Do not allow gas cylinders (especially oxygen) to empty in use - this can cause unbalanced pressures and reverse flow of gasses. An adequate cylinder of manifold system should be provided for large gas usage operations with 3/8" hose for larger size tips. Approximate heat output B.T.U./HR. per cubic foot: acetylene 1470, propane 2498, Mapp® 2406 propylene 2371, natural gas 1000.
SCFH, std. cu. ft. per hr. PSIG, pounds per square inch guage.

WARNING:
Do not operate this equipment until you fully understand its safe and proper use. The safe and effective use of the equipment depends on the user fully understanding and carefully following practical time-tested safety operation instructions to prevent and avoid unnecessary painful injuries and costly property damages and losses.

Read all operating instructions carefully before using equipment. Do not light torch until all connections are leak tight. Purge out torch before lighting.

Heating Tips Oxy-Acetylene or Fuel Gas	Tip Size	Acetylene/Fuel Gas Pressure*** Range PSIG	Oxygen Pressure*** Range PSIG	Acetylene SCFH	Oxygen SCFH
Type 11, 12 Victor Type Seat Type 11-H+ Harris Type Seat Type 911 Airco Type Seat	5	7-10	10-15	6-20	7-25
	6	7-10	10-15	14-40	15-45
	8	10-15	20-30	30-80	35-90
	10*	12-15	25-40	40-100	45-115
	12*	12-15	40-60	60-150	70-170
	15*	12-15	40-60	90-220	100-250
Type 28, 29 Victor Type Tip Type 7928-79+ 7928-43 Harris Type Tip Type 37 Airco Type Tip	2	5-7	5-8	3-9	4-10
	4	5-7	8-12	7-20	10-20
	6	8-12	10-15	14-40	15-45
	8	10-15	20-30	30-80	35-90
Type 13, 17 Victor Type Seat	15,30	8-12	10-20	15, 30	17, 33

+ Oxy/Acetylene/equal pressures for Harris type tips

Heating Tips Fuel Gas (Not Acetylene)	Tip Size	Oxygen Pressure*** PSIG	Fuel Gas Pressure*** PSIG	Consumption, SCFH	
				Oxygen	Fuel Gas
Type 45 Victor Type Tip	10*	70/100	15/25	350/480	150/200
	15*	90/120	20/35	600/800	250/350
Type 945 Airco Type Tip	20*	100/150	30/50	900/1150	400/500
2290-H Harris Type Tip	2290-1H	10/25	4/12	160/320	40/80
	2290-2H*	15/45	7/22	220/520	55/130
	2290-3H*	25/70	8/25	340/920	85/230
	2290-4H*	50/110	10/30	640/1300	160/325
	2290-5H*	60/135	14/40	720/1600	180/400

***** Use 3/8" hose on large tips for more gas flow.
****** Type 12 for fuel gas only (Not Acetylene)
*****IMPORTANT:** Use maximum pressure on large heating tips to avoid backfire and flashback conditions from low gas flows. Fuel gas flame must have excessive smoking cleared to provide adequate gas flow increase fuel regulator pressure enough to clear smoke from flame.
SCFH, std. cu. ft. per hr. PSIG, pounds per square inch guage

Troubleshooting Victor Cutting Attachments & Cutting Torches

Problems, Possible Causes, and Solutions

CAUSES	CORRECTIONS
1. Preheat flame pops periodically.	
Tip Nut Loose	Tighten the tip nut to 15 ft. lbs. of torque.
Damaged seating surface on tip or torch head	Replace the tip or ream out the head.
2. Preheat flame changes when the high pressure oxygen valve is open.	
Faulty cutting oxygen valve.	Replace the cutting oxygen valve.
Worn or missing packing in the cutting oxygen valve.	Replace the cutting oxygen valve.
Internal Leakage.	Test the torch for internal leaks and repair as required.
Improper oxygen presence.	Check the oxygen setting.
3. Torch performance is sluggish or penetration is insufficient.	
Wrong tip size.	Check for proper tip.
Oxygen regulator not delivering proper pressure.	Replace the cylinder or regulator.
Restriction in cutting oxygen orifice.	Clean the cutting oxygen orifice.
Oxygen hose pinched or clogged.	Clear the hoses.

4. Neutral preheating flame cannot be adjusted or low pressure oxygen supply cannot be shut off.

(Cutting attachments) Cone end between cutting attachment and torch is not seating properly.	Replace the cone end or ream the head.
Cone end o-rings worn or missing.	Replace the o-rings.

5. Leak around the valve stem.

Loose packing nut.	Tighten the packing nut.
Damaged packing.	Replace the valve stem assembly.

6. Flame flickers during use.

Loose stainless steel balls in the control valves.	Replace the valve stem assembly.

7. Torch pops excessively.

Obstructions in tip.	Clean or replace tip.
The regulator is delivering insufficient gas.	Replace the cylinder or regulator.
Low cylinder pressure.	Replace the cylinder.
Improper regulator setting.	Check for improper regulator setting.
Internal leaks in torch.	Test the torch per cutting torches test procedure.

8. Difficulty in maintaining a neutral flame.

• Regulator not functioning properly.	• Test and repair the regulator.
• Hoses pinched or clogged.	• Clear the hoses.
• Control valves damaged.	• Replace the control valves.

CAUTION: Welding apparatus that is improperly maintained or repaired can be dangerous. Some parts and accessories from one manufacturer may fit apparatus from other manufacturers, but the assembly may not conform to the standards of either manufacturer. For your own safety, specify and use parts and attachments from only one manufacturer in any assembly according to that manufacturer's specifications.

Service and repair of welding apparatus should be performed only by a qualified repair technician. Improper service or repair, or modification of a product could result in damage to the product or injury to the operator

GUIDE TO
OXY-ACETYLENE WELDING EQUIPMENT

BACKGROUND

The use of gas welding dates back to the middle 1800's where a mixture of Oxygen And Hydrogen were used to produce a hot flame that was used in the making of jewelry. It wasn't until the late 1890's when the gas Acetylene became available that gas welding developed into the process that we know today. Acetylene is a gas that is manufactured by mixing Calcium Carbide,(a by product of the electric furnace steel making process) with water. Acetylene when burned alone can produce a flame temperature of about 4000 deg. F. With the addition of Oxygen a flame temperature in excess of 6000 deg. F. can be achieved, making Acetylene ideal for welding and cutting. An Oxy-Acetylene outfit is portable, less expensive and more versatile than a electric welding set up. By using the proper tips, rods and fluxes, almost any metal can be welded, heated or cut using the Oxy-Acetylene process.

There are many components that make up the Oxy-Acetylene outfit such as cylinders, regulators, hoses etc. The following is a typical outfit listing each component with a brief description of each.

CYLINDERS

Oxygen and Acetylene are stored under pressure in steel cylinders . They are sized by the cuft. of either Oxygen or Acetylene that they hold.

Cylinders should be tested regularly with the date of the last test stamped on the top of the cylinder. Cylinders should always be secured and used in the upright position. When a cylinder is not being used, the valve cap should always be in place.

OXYGEN CYLINDERS

These cylinders are made of steel and are usually painted green. They range in size from less than 20 cuft. To over 300 cuft and contain compressed Oxygen at pressures that can be as high as 2200 psig. All cylinders have valves and (except the small "R" tank) are fitted with a screw on steel cap that protects the cylinder valve when the cylinder is not in use. If Oxygen comes into contact with oil or grease, it will burst into flame. Never use oil or grease on Oxygen cylinder valves or regulators. Make sure hands and gloves are free of oil and grease before handling cylinders. Crack open the cylinder valve then close it before installing the regulator to clear the valve of any dirt. With the regulator installed, always crack the cylinder valve open first, then open it fully. This will lessen the chance of recompression which is caused by high cylinder pressure entering the regulator, heating up and damaging the regulator.

ACETYLENE CYLINDERS

These cylinders contain Acetylene under pressure, are painted black, (small "B" and "MC" tanks can be gray, silver or red) made of steel and have cylinder valves. They range in size from 10 to almost 400 cuft capacity. The cylinders contain a porous filler material which is wetted with acetone that allows the Acetylene to safely be contained in the cylinder at 250 psig. Always use an Acetylene cylinder in the up right position so you don't draw any of the acetone out of the tank. Only open the cylinder valve 1 to 1 1/2 turns, leaving the valve wrench on the valve in the event it has to be shut off quickly. Acetylene should never be used at a pressure that exceeds 15 psig as it becomes highly unstable which, depending on the condition, could cause it to decompose and explode. As with the Oxygen cylinder, make sure the cylinder valve is clean before installing the regulator.

REGULATORS

With the pressure in a full Acetylene cylinder at 250 psig and a full Oxygen cylinder at 2200 psig, a way is needed to lower these cylinder pressures to desired working pressures for use in the torch. This is accomplished by using an adjustable pressure reducing regulator. The regulator will also maintain a steady working pressure as the cylinder pressure drops from use.

Basically, regulators work by admitting the high cylinder pressure through a valve which is operated by a flexible diaphragm. By turning the regulator adjusting knob or screw in or out causes a spring in the regulator to operate the diaphragm which opens or closes a valve in the regulator. This in turn regulates the outlet pressure and flow. By turning the adjusting knob in you increase the flow and pressure, out decreases the flow and pressure. Most regulators have two gauges. One shows the inlet pressure from the cylinder (the high pressure gauge) and the other (low pressure gauge) shows the working pressure being supplied from the regulator. There are regulators that are made for heavy duty or rough service that are not equipped with gauges, (referred to as gaugeless) and have a scale in the regulator body that is used to make pressure adjustments.

There are two general types of regulators, single stage and two stage. Both perform the same function but the two stage regulator will supply a more constant pressure as the cylinder pressure falls by compensating for any drop in cylinder pressure better than will the single stage unit. Also, two stage regulators are usually more heavy duty in construction and will last longer in heavy duty use and require less maintenance than the single stage units. Two stage regulators can be identified by their second pressure chamber where single stage units have only one. Oxygen and Acetylene regulators

connect differently to their cylinders so they can not be mixed up. Oxygen regulators have right hand threads and regulators for Acetylene and other fuel gases have left hand threads. You will notice a groove around fuel connections which indicate a left handed thread. Finally all outlet (low pressure) gauges on Acetylene regulators have their gauge scales marked in red starting at 15 psig. This is to act as a reminder not to use Acetylene at pressures over 15 psig as explained in the section on Acetylene cylinders.

WELDING HOSES

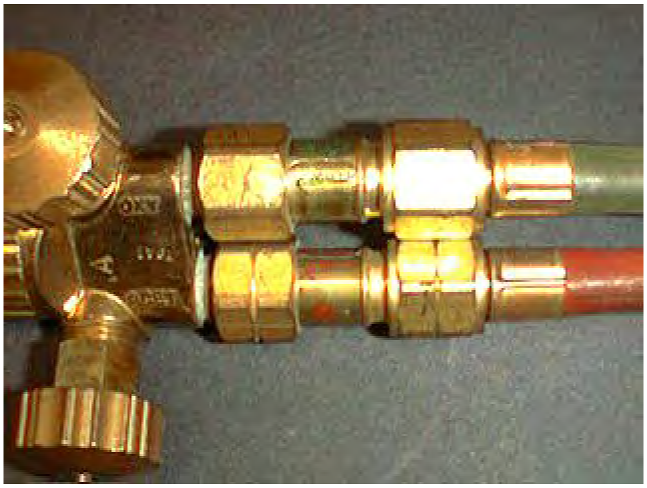
The cylinder regulators and torch are usually connected together by double line rubber hoses. Double line hose is know as type VD. The Oxygen line is green, the fuel line red. Hoses are available in four sizes, 3/16, 1/4, 3/8 and 1/2 inch I.D. There are different grades of double line hose used for Acetylene. They are:

- Non-oil resisting rubber cover
- RM- carries both a non-oil and flame and oil resisting cover
- (for use with all fuel gases & Acetylene) flame and oil resisting cover.

Grades R & RM should be marked for Acetylene only. Grade T should be marked fuel gas. All hoses should be marked as to their service level (light, standard or heavy). Date of manufacture, maximum working pressure, (200 psig) nominal I.D size and if it meets RMA/CGA IP-90 (Rubber Manufactures Association, Compressed Gas Association) specifications for rubber welding hose. The fittings on the hoses are marked as to right and left handed threads.

Single line hose come in three grades, L, light duty, S, standard duty and H, heavy duty. And are also limited to a working pressure of 200 psig.

CHECK VALVES

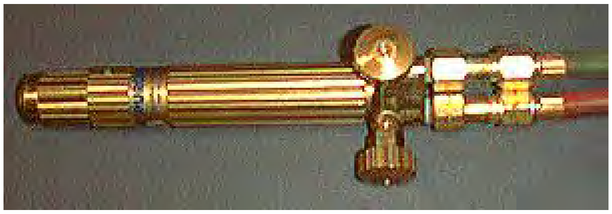


For combustion to occur, fuel and Oxygen have to mix. This should only happen in the torch mixer or the torch tip. Sometimes, due to improper operation, fuel and Oxygen could feed back into the hoses and cause combustion in the hoses or regulators. (not good!) Check valves when installed between the hoses and torch prevent this back flow as they close if a reverse flow starts. Check valves should be used with all torches.

FLASH BACK ARRESTORS

A flashback, which is a rapid high pressure flame in the hose can occur if there aren't any check valves or the check valves fail to operate due to improper installation. Once a flashback starts, check valves can not stop it, but a flashback arrestor will! The arrestor connects the same as the check valves, in the hose at the torch or regulator and contains a trap that is spring loaded that cuts off the gas flow in the event of a flashback. Both check valves and flashback arrestors are like they say, cheap insurance and should be included on every Oxy-Acetylene outfit!

TORCHES



The torch assembly consists of the handle, oxygen and fuel gas valves and mixing chamber. Welding tips or a cutting attachment can be used with the handle allowing it to be used for welding, heating and cutting operations. Oxygen and fuel gas flow through tubes inside the handle which blend in the mixing chamber or tip. It is at the tip that the mixed gases are ignited. There are two basic mixer types, the equal or medium pressure type (also known as balance or positive pressure type) and the injector type. The equal pressure type is the most common and is used with fuel gas pressures that are above 1 psi. Oxygen and fuel gas enter the torch at almost equal pressures. The injector type is used when fuel gas pressures are less than 1 psi. In this type, Oxygen at high pressure pulls the fuel gas into the mixing chamber .

WELDING AND CUTTING TIPS

The welding tip is mounted on the end of the torch handle and through it the oxygen and fuel gas mixture feed the flame. Tips are available in a variety of shapes and sizes to fit most any welding job and are identified by number. The larger the number, the larger the hole in the tip and the thicker the metal that can be welded or cut. Welding tips have one hole and cutting tips have a centrally located hole with a number of smaller holes located around it in a circular pattern. The cutting Oxygen comes from the center hole with the preheat flame coming from the holes around it. Many factors determine the size tip to use, but mainly the thickness of the metal to be welded or cut determines which tip size to use. The attachments at the end of this article will serve as a guide to tip selection.

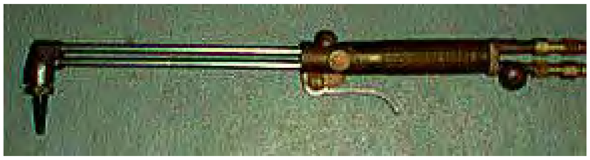
ACETYLENE WELDING TIPS

Metal Thickness	**Tip Size**	**Rod Size**	**Oxygen Pressure**	**Acetylene Pressure**
In.	No.	In.	PSI	PSI
1/64 - 1/32	000	1/16	3	3
1/32 - 3/64	00	1/16	3	3
1/32 - 5/64	0	3/32	3	3
3/64 - 3/32	1	1/8	3	3
1/16 - 1/8	2	5/32	4	4
1/8 - 3/16	3	3/16-1/4	4	4

CUTTING ATTACHMENTS

A cutting attachment connects to the end of the torch handle in place of the welding tip and allows for the cutting of metal up to 8 inches thick. For cutting metal over 8 inches, the use of a cutting torch instead of a cutting attachment should be used. The fuel gas valve on the torch handle is used to adjust the fuel. The Oxygen valve on the torch handle is opened full and the Oxygen flow for the preheat flame is adjusted using the Oxygen valve on the cutting attachment. The cutting Oxygen is controlled by the lever operated valve on the attachment.

CUTTING TORCH



The cutting torch is connected to the hoses in place of the welding handle and is used for cutting thicker metal than can be cut with the cutting attachment, or for heavy duty cutting work. The cutting torch like the welding handle is equipped with Oxygen and fuel gas valves with a lever operated Oxygen valve that controls the flow of cutting Oxygen to the tip. (Center hole in the cutting tip) In the two tube model, Oxygen and fuel gas mix and flow to the tip in the larger bottom tube with the cutting Oxygen flowing to the tip in the top tube. In three tube models, Oxygen and fuel gas flow to the tip in the bottom tubes and cutting Oxygen flows to the tip in the top tube.

WELDING GOGGLES & GLOVES

Proper welding gloves and goggles must be worn to provide protection when using a Oxy-Acetylene outfit. Gloves should be made for welding use. Goggles (or face shield) must be worn to protect the eyes from sparks and hot metal, especially when cutting metal. If you ever try to weld or cut without using goggles or a face shield, try this first. Stand in front of the outfit, close your eyes tight and adjust the regulators, that's if you can find them !!! (point made I hope!!) The proper lens shade should be selected in order to provide the maximum amount of protection. The following chart lists the recommended shade of lens that should be used for various welding and cutting operations.

Application	**Lens shade no.**
Brazing	3 or 4
Light cutting (up to 1")	3 or 4
Medium cutting (1 to 6")	4 or 5
Heavy cutting (over 6")	5 or 6
Light welding (up to 1/8)	4 or 5
Medium welding (1/8 to 1/2)	5 or 6
Heavy welding (over 1/2)	6 or 8

The Brazing Book

This book contains a significant amount of information on the process of brazing. It was created by Handy & Harman to assist both the novice brazier and the seasoned engineer. For years, this publication has been well received and a very useful tool. This publication has been updated to incorporate the many changes that have occurred within the industry. However, the purpose of this book remains the same: to expand the applications of brazing by relaying the many advantages of it as a metal-joining method -- while being quite candid about its limitations. And we highlight the many people and industries that are now using brazing wherever possible to increase their manufacturing efficiencies.

For ease of understanding, we've divided the book into five main sections. Section one, "The Idea of Brazing," explains exactly what brazing is, where to use it, and how to perform it properly. Section Two, "Brazing in Action," presents detailed photographic case histories illustrating some of the many applications in which brazing is used today. Section Three, "Choices in Brazing Materials," lists and describes the many brazing products available from Handy & Harman and features useful selection charts to help you choose the best filler metals and fluxes for your particular brazing application. For your convenience, we've also included a number of technical reference tables and related information. Section Four, "Available Reference Materials," lists a variety of other brazing related information available to further assist you in your brazing operations. We know you'll find The Brazing Book informative and helpful. We hope you'll find it interesting as well.

What is brazing?

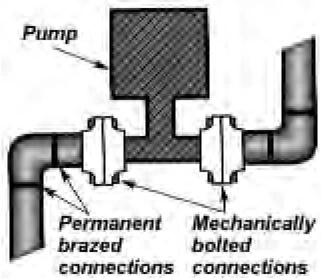
Brazing is the joining of metals through the use of heat and a filler metal – one whose melting temperature is above 840°F (450°C) but below the melting point of the metals being joined. (A more exact name for the brazing process discussed in this book may be "silver brazing," since in most cases the filler metal used is a silver alloy. To remain brief, we'll use the term "brazing" throughout this book, with the understanding that we are referring to a torch brazing process with a silver-bearing filler metal. Where exceptions occur, it will be noted.) Brazing is probably the most versatile method of metal joining today, for a number of reasons. Brazed joints are strong. On non- ferrous metals and steels, the tensile strength of a properly made joint will often exceed that of the metals joined. On stainless steels, it is possible to develop a joint whose tensile strength is 130,000 pounds per square inch. (896.3 megapascals [MPa]). Brazed joints are ductile, able to withstand considerable shock and vibration. Brazed joints are usually easy and rapidly made, with operator skill readily acquired. Brazing is ideally suited to the joining of dissimilar metals. You can easily join assemblies that combine ferrous with nonferrous metals, and metals with widely varying melting points. Brazing is essentially a one-operation process. There is seldom any need for grinding, filing or mechanical finishing after the joint is completed. Brazing is performed at relatively low temperatures, reducing the possibility of warping, overheating or melting the metals being joined. Brazing is economical. The cost- per-joint compares quite favorably with joints made by other metal joining methods. Brazing is highly adaptable to automated methods. The flexibility of the brazing process enables you to match your production techniques very closely to your production requirements. With all its advantages, brazing is still only one of the ways in which you can join metals. To use brazing properly, you must understand its relationship to other metal jointing methods. What are some of those methods and which should you use where?

The versatility of brazing.

- Strong joints
- Ductile joints
- Ease of operation
- Suited to dissimilar metals
- One-operation process
- Requires low temperatures
- Economical
- Highly adaptable to automation

The many ways to join metals.

Brazing, as we've noted, relies on heat and a filler metal to join metals. There is nothing unique about this. Welding and soldering are similar in these respects. And metals can also be joined efficiently and economically without the need for heat or a filler metal at all, by mechanical fastening or adhesive bonding. When would you use brazing, rather than one of these other methods? It depends on the circumstances. Let’s start our evaluation of brazing as a metal joining method by eliminating those situations were brazing is generally *unsuitable.* The first of these situations is the *non-permanent* joint. This is the joint that’s made with future disassembly in mind. (For example, a pump connected to a piping assembly.)



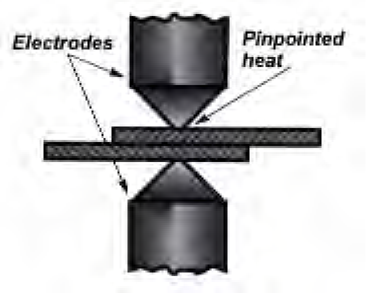
The pipes won't wear out, but some day the pump will. It's easier to disassemble a threaded or bolted pump connection than a brazed con- nekton. (You can "de-braze" a brazed joint if you have to, but why plan on it?) For the typical non-permanent joint, mechanical fastening is usually the most practical method. There's another kind of joint where brazing will likely be your last, rather than your first, consideration. And that is the permanent, but *low-strength* joint. If you're joining metal assemblies that won't be subjected too much stress or strain, there are frequently more economical ways to join them than by brazing. (Mechanical fastening, for example, or soft soldering or adhesive bonding.) If you are selecting a method to seal the seams of tin cans, there is nothing to stop you from brazing. Yet soft-soldering would be perfectly adequate for this low-stress type of bond. And soft-soldering is generally less expensive than brazing. In these two areas – the non- *permanent* joint and the permanent but low-strength joint – other joining methods are adequate for the job and usually more economical than bronzing.

Where does brazing fit in?

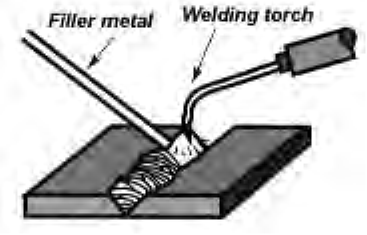
Consider brazing hen you want *permanent* and *strong* metal-to-metal joints. Mechanically-fastened joints (threaded, staked, riveted, etc.) generally don’t compare to brazed joints in strength, resistance to shock and vibration, or leak-tightness. Adhesive bonding and soldering will give you permanent bonds, but generally neither can offer the strength of a brazed joint – strength equal to or greater than that of the base metals themselves. Nor can they, as a rule, produce joints that offer resistance to temperatures above 200°F (93°C). If you want metal joints that are both permanent and strong, it's best to narrow down your consideration to *welding* and *brazing.* Welding and brazing both use heat. They both use filler metals. They can both be performed on a production basis. But the resemblance ends there. They work differently, and you need to understand the nature of that difference to know which method to use where.

How welding works.

Welding joins metals by melting and *fusing* them together, usually with the addition of a welding filler metal. The joints produced are strong, usually as strong as the metals joined or even stronger. In order to fuse the metals, a concentrated heat is applied directly to the joint area. This heat is high temperature. It must be – in order to melt the "base" metals (the metals being joined) and the filler metals as well. *So welding temperatures start at the melting point of the base metals.* Because welding heat is intense, it is impractical to apply it uniformly over a broad area. Welding heat is typically localized, *pinpointed* heat. This has its advantages. For example, if you want to join two small strips of metal at a single point, an electrical resistance welding setup is very practical.



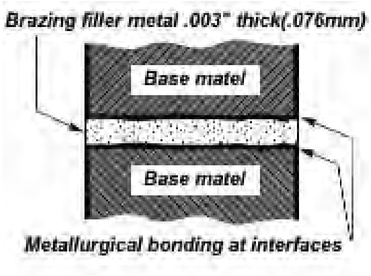
This is a fast, economical way to make strong, permanent joints by the hundreds and thousands. However, if the joint is *linear,* rather than *pinpointed,* problems arise. The localized heat of welding tends to become a disadvantage. For example, suppose you want to butt- weld two pieces of metal – start by beveling the edges of the metal pieces to allow room for the welding filler metal. Then weld, first heating one end of the joint area to melting temperature, then slowly traveling the heat along the joint line, depositing filler metal in synchronization with the heat. This is a typical conventional welding operation. Let's look at its characteristics.



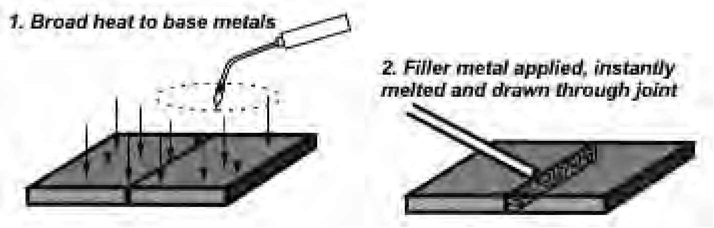
It offers one big plus – strength. Properly made, the welded joint is at least as strong as the metals joined. But there ore minuses to consider. The joints made at high temperatures, high enough to melt both base metals and filler metal. High temperatures can cause problems, such as possible distortion and warping of the base metals or stresses around the weld area. These dangers are minimal when the metals being joined are thick. But they may become problems when the base metals are thin sections. High temperatures are expensive as well since heat is energy, and energy costs money. The more heat you need to make the joint, the more the joint will cost to produce. Now consider the automated process. What happens when you join not one assembly, but hundreds or thousands of assemblies? Welding, by its nature, presents problems in automation. We know that a resistance weld joint made at a single point is relatively easy to automate. But once the point becomes a line – a *linear* joint – the line has to be *traced.* It's possible to automate this tracing operation, moving the joint line, for example, past a heating station and feeding filler wire automatically from big spools. But this is a complex and exacting setup, warranted only when you have large production runs of identical parts. Of course, welding techniques continually improve. You can weld on a production basis by electron beam, capacitor discharge, friction and other methods. But these sophisticated processes usually call for specialized and expensive equipment and complex, time consuming setups. They're seldom practical for shorter production runs, changes in assembly configuration or – in short – typical day-to- day metal joining requirements.

How brazing works.

A brazed joint is made in a completely different way from a welded joint. The first big difference is n temperature. Brazing *doesn't melt* the base metals. *So brazing temperatures are invariably lower than the melting points of the base metals.* And, of course, always significantly lower than welding temperatures for the same base metals. If brazing doesn't fuse the base metals, how does it join them? It joins them by creating a metallurgical bond between the filler metal and the surfaces of the two metals being joined.



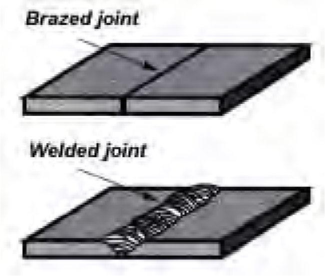
The principle by which the filler metal is drawn through the joint to create this bond is *capillary action.* In a brazing operation, *you* apply heat broadly to the base metals. The filler metal is then brought into contact with the heated parts. It is melted instantly by the heat in the base metals and drawn by capillary action completely through the joint.



This, in essence, is how a brazed joint is made. What are the advantages of a joint made this way?

Advantages of a brazed joint.

First, a brazed joint is a strong joint. A properly-made brazed joint (like a welded joint) will in many cases be as strong as or stronger than the metals being joined. Second, the joint is made at relatively low temperatures. Brazing temperatures generally range from about 1150°F to 1600°F (620°C to 870°'C). Most significant, the base metals are never melted. Since the base metals are not melted, the can typically retain most of their physical properties. And this "integrity" of the base metals is characteristic of all brazed joints, of thin-section as well as thick-section joints. Also, the lower heat minimizes any danger of metal distortion or warping. (Consider too, that lower temperatures need less heat which can be a significant cost-saving factor.) And important advantage of brazing is the ease with which it joins dissimilar metals. If you don't have to melt the base metals to join them, it doesn't matter if they have widely different melting points. You can braze steel to copper as easily as steel to steel. Welding is a different story. You must melt the vase metals to fuse them. So if you try to weld copper (melting point 1981°'F/1083°C) to steel (melting point 2500°F/1370°C), you have to employ rather sophisticated, and expensive, welding techniques. The total ease of joining dissimilar metals through conventional brazing procedures means you can select whatever metals are best suited to the function of the assembly--knowing you'll have no problem joining them no matter how widely they vary in melting temperatures. Another advantage of a brazed joint is its good appearance. The comparison between the tiny, neat fillet of a brazed joint and the thick, irregular bead of a welded joint is like night and day.



This characteristic is especially important for joints on consumer products, where appearance is critical. A brazed joint can almost always be used *as is,* without any finishing operations needed. And that too is a money-saver. Brazing offers another significant advantage over welding in that brazing skills can usually be acquired faster than welding skills. The reason lies in the inherent difference between the two processes. A linear welded joint has to be traced with precise synchronization of heat application and deposition of filler metal. A brazed joint, on the other hand, tends to "make itself" through capillary action. (A considerable portion of the skill involved in brazing actually lies in the design and engineering of the joint.) The comparative quickness with which a brazing operator may be trained to a high degree of skill is an important cost consideration. Finally, brazing is relatively easy to automate. The characteristics of the brazing process – broad heat applications and ease of positioning of filler metal – help eliminate the potential for problems. There are so many ways to get heat to the joint automatically, so many forms of brazing filler metal and so many ways to deposit them, that a brazing operation can easily be auto- mated to the extent needed for almost any level of production.

Brazing advantages

- Joint strength
- Lower temperatures/lower cost
- Maintains integrity of base metals
- Dissimilar metals easily joined
- Good joint appearance
- Operator skill easily acquired
- Process easily automated

Which Joining method is the best?

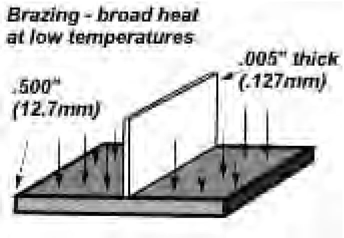
As we've indicated, when you want to make strong and permanent metal joints, your choice will generally narrow down to welding or brazing. So, which method is best? It depends entirely on the circumstances. The key factors in making a decision will boil down to the *size* of the parts to be joined, the *thickness* of the metal sections, *configuration* of the joint, *nature* of the base metals, and the *number* of joints to be made. Let's consider each of them.

How big is the assembly?

Welding is usually more suited to the joining of large assemblies than brazing. Why? Because in brazing the heat must be applied to a broad area, often to the entire assembly. And if the assembly is a large one, it's often hard to heat it to the flow point of the filler metal as the heat tends to dissipate faster than you build it up. You don't meet this limitation in welding. The intense localized heat of welding, sometimes a drawback, becomes an advantage in joining, a large assembly. So does welding's ability to trace a joint. There's no way to establish exactly the point at which size of assembly makes one metal joining method more practical than another. There are too many factors involved. For example, if the assembly is unable to be brazed in open air (torch, induction, etc.) due to size, a furnace or dip brazing process may eliminate the size consideration. However, you can still use this rule-of-thumb as a starting point: Large assembly-weld, if the nature of the metals permits. Small assembly-braze. Medium-sized assembly-experiment.

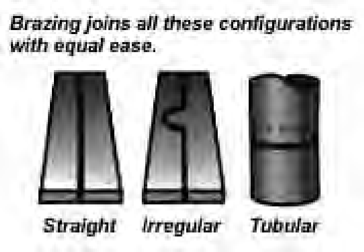
How thick are the metal sections?

Thickness of base metal sections is an important consideration in selecting your metal joining method. If both sections are relatively thick – say .500" (12.7mml – either welding or brazing can produce a strong joint. But if you want to make a T-joint, bonding a .005" (.127mm) thick sheet metal section to half-inch stock for example, brazing is the better choice. The intense heat of welding is likely to burn through, or at least warp, the thin section. The broader heat and lower temperature of brazing allows you to join the sections without warpage or metal distortion.



What's the joint configuration?

Is the joint a "spot" or a "line" 2 A spot joint made at one point can be accomplished as easily by welding as by brazing. But linear joint – all other things being equal – is more easily brazed than welded. Brazing needs no manual tracing. The filler metal is drawn through the joint area by capillary action, which works with equal ease on any joint configuration.



What metals are you joining?

Suppose you’re planning a two- section metal assembly. You want high electrical conductivity in one section, high strength and corrosion resistance in the other. You want to þ se copper for conductive, and stainless for strength and corrosion resistance. Welding this assembly »ill present problems. As we've seen, you have to melt both metals to fuse them. But stainless melts at a much higher temperature than copper. The copper would completely melt and flow off before the stainless came anywhere close to its melting temperature. Brazing these dissimilar metals offers no such obstacle. All you have to do is select a brazing filler metal that is metallurgically compatible with both base metals and has a melting point lower than that of the two. You get a strong joint, with minimal alteration of the properties of the metals. The point to remember is that brazing joins metals *without melting them,* by metallurgically bonding at their interfaces.

The integrity and properties of each metal in the brazed assembly are retained with minimal change. If you plan to join dissimilar metals – think brazing.

How many assemblies do you need?

For a single assembly, or a few assemblies, your choice between welding and brazing will depend largely on the factors discussed earlier – size of parts, thickness of sections, joint configurations, and nature of base metals. Whether you braze or weld, you'll probably do the job manually. But when your production needs run into the hundreds, or thousands (or hundreds of thousands), production techniques and cost factors become decisive. Which method is best – for *production* metal joining? Both methods can be automated. But they differ greatly in flexibility of automation. Welding tends to be an all-or-nothing proposition. You weld manually, one-at-a-time, or you install expensive, sophisticated equipment to handle very large runs of identical assemblies. There's seldom a practical in-between. Brazing is just the opposite. You can braze "one-at-a-time" manually, of course. But you can easily introduce simple production techniques to speed up the joining of several hundred assemblies. As an example, many assemblies, pre-fluxed and bearing pre-placed lengths of filler metal, can be simultaneously heated and brazed in a furnace. When you get into larger runs, it may become practical to rig up a conveyor which can run the assemblies past banks of heating torches and brazing filler metal can be applied to the joint in a pre- measured amount. And there are endless "in-between" possibilities, a good many of which you can accomplish with relatively inexpensive production devices. The point to keep in mind is that brazing is flexible. You can automate it on a step-by-step basis, at each step matching your automation investment to your production requirements.

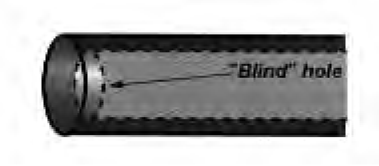
Welding vs. Brazing considerations

- Size of assembly?
- Thickness of base metal sections?
- Spot or line joint?
- Metals being joined?
- Final assembly quantity needed

Brazing as a means to make a part.

So far, we've been talking about brazing as a way of joining two or more metals into a permanent assembly. And we've limited our discussion to the situations where you have a metal assembly in mind from the outset, from initial product concept through finished piece. Now let's discuss brazing from a very different point of view. Think about the parts your company fabricates, and consider where any of those parts now made as monolithic units, might not be made more efficiently as brazed assemblies. Consider this real-life story...

A company was fabricating thousands of small, closed-end metal cylinders. The part looked like this:



For years the cylinders were machined out of solid bar stock, with considerable labor required to drill and bore the blind holes. Finally, someone suggested that the cylinder was actually two parts--bar stock cut-offs brazed into lengths of stock tubing:

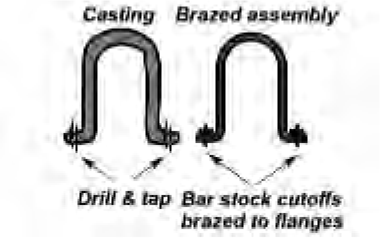
The assembly is a lot less expensive to make than the machined part and it works just as well.

Think Brazing at the beginning.

The time to consider brazing is at the beginning, when you're first planning or designing and metal component. Ask yourself if the part should be made as a single unit, or if it can better be made as an assembly of simple components. The "assembly" approach may help you eliminate expensive casting, forging and machining operations. It may save materials. It may enable you to use low-cost stock forms--sheet, tube, rod, stampings or extrusions. It will almost invariably be lighter in weight than the monolithic part, and will probably work better as the metals in the assembly can be selected to match their functions. Let's look at some typical metal "parts." First we'll see how they're made be conventional casting, forging and machining methods. And then we'll see how they could be made better and more economically as brazed assemblies.

From casting to sheet metal.

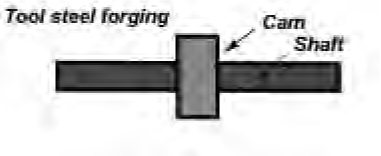
You're designing housing, with threaded holes in the flange. You could make it as a casting. But consider instead making it as a brazed assembly, joining bar stock sections to a sheet metal deep draw:



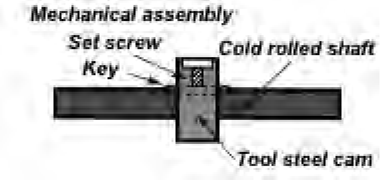
The brazed assembly works just as well as the casting. And it's a lot cheaper to make, because you're putting the thickness only where you really need it--in the flange and not the shell. You save weight, materials and labor.

From forging to brazing.

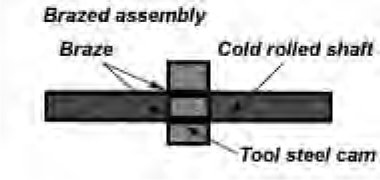
You're planning a part--a hardened cam on a steel camshaft. Should you machine the unit out of a solid bar of tool steel? That's a lot of lathe chips. Perhaps forge the piece and then finish-machine it?



Still a lot work. After hardening, the cam has to be drawn and the shaft ends annealed. How about making the cam and shaft separately and then join them mechanically as an assembly?



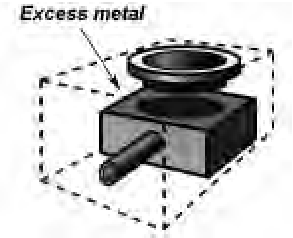
You're on the right track. By substituting cold rolled for tool steel in the shaft, you're saving on material cost. But machining is still somewhat involved, and locking device, such as a set screw, is subject to loosening under vibration. Now try the "assembly" approach again, but this time use a brazed joint instead of a mechanical one.



Simplest of all. No keyway, no key, no set screw. Minimum material, minimum labor and a strong, permanent, vibration-proof bond,

The awkward elbow.

Extensions or projections on metal parts require excessive material (expensive!), and then a lot of work to machine away the unwanted metal (twice as expensive!). Consider what happens when you make an elbow shaped part from solid stock...

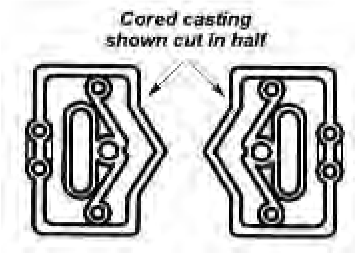


You're paying for metal you don't want, and the labor of getting rid of it. There's an easier way. Make the "part" as a brazed assembly, joining together standard tubing and bar stock components:

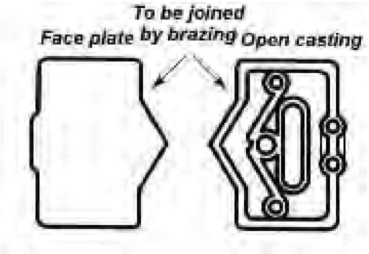
The assembly will be just as strong as the machined part. And you'll save materials, labor and weight. (The more awkward and complex the extension, the more you'll save.)

From hard to easy.

You have to design a leak-tight component, with complex configuration. You can plan it as a cored casting...



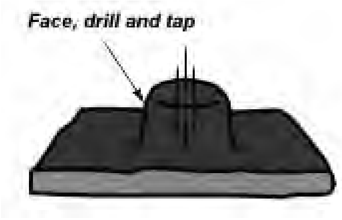
It will be lead-tight, but a cored casting is an expensive one. An open casting is a lot cheaper to make. So why not make it that way?



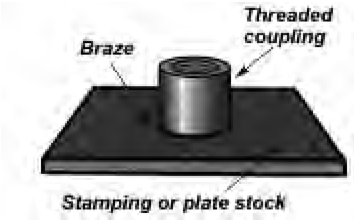
By using brazing, you've replaced the complex cored casting with a simple open casting and a metal stamping. Machining is easier, and brazing's capillary action assures you of a leak-tight bond.

From casting to stock parts.

Let's say you're designing a base plate with a threaded coupling. You can make it in one piece as a casting...



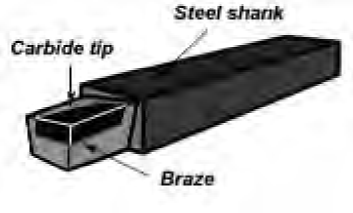
Material cost is low, but material choice is limited. Weight is excessive, machining extensive, and the finished part may be weak and brittle. Consider making the "part" as a brazed assembly of stock elements...



Machining is minimal--the base plate is a stamping and the coupling a screw machine part. Weight is down to the bone, too, because the thickness is only where it's needed, in the treaded coupling. Material can be matched to function. And the assembly will undoubtedly be stronger than the casting.

Two metals are better than one.

The ability of brazing to join dissimilar metals is helpful in many applications, but in some instances it's quite critical. A classic example is the carbide metal-cutting tool. The tool could be made entirely of carbide. But carbide is expensive. What's more, though carbide is fine for the cutting tip, you don't really want to use it for the tool shank. It's too hard and brittle to withstand shock. Brazing solves the problem...



By brazing, you've reduced material cost--obviously. But even more--you're now using metals perfectly suited to their functions. Hard carbide at the cutting edge, and shock-resistant tool steel for the shank.

Freedom for the designer.

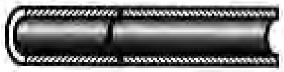
We started this section with a question: "When do you think brazing?" And we've indicated, through just a few of the many possible examples, that you think brazing at the beginning--at the design stage. The fact is--brazing liberates the designer. It enables him to design for function, for light weight, for selective use of metals, and for production economy, The designer who's fully aware of the possibilities of brazing thinks less and less in terms of castings, forgings and parts machined from solid metal, He thinks more and more in terms of brazed assemblies, which combine plate or sheet stock, standard tubing and bar, stampings and screw machine parts, Assemblies based on the use of such elements are generally lighter in weight, less expensive to fabricate, and at least equal in performance to metal parts made as monolithic units.

Types of brazed joints.

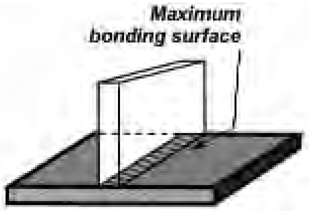
What type of brazed joint should you design? There are many kinds of joints. But our problem is simplified by the fact that there are only two basic types – the butt and the lap. The rest are essentially modifications of these two. Let's look first at the butt joint, both for flat and tubular parts.

Butt joint - flat parts

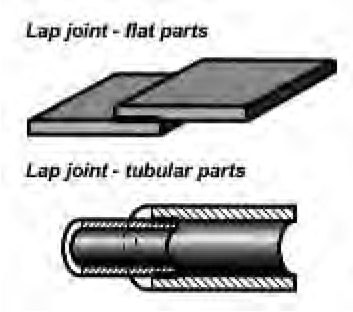
Butt joint - tubular parts (cutaway)



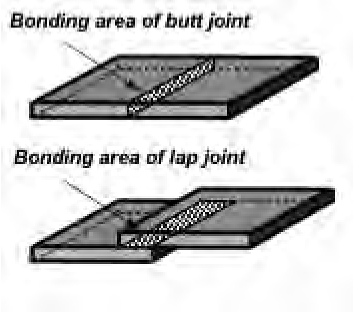
As you can see, the butt joint gives you the advantage of a single thickness to the joint. Preparation of this type of joint is usually simple, and the joint will have sufficient tensile strength for a good many applications. However, the strength of the butt joint does have limitations. It depends, in part, on the amount of bonding surface, and in a butt joint the bonding area can't be any larger than the cross-section of the thinner member.



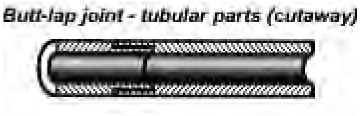
Now let’s compare this with the lap joint, both for flat and tubular parts.



The first thing you'll notice is that, for a given thickness of base metals, the bonding area of the lap joint can be larger than that of the butt joint and usually is. With larger bonding areas, lap joints can usually carry larger loads.



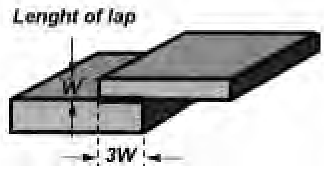
The lap joint gives you a double thickness at the joint, but in many applications (plumbing connections, for example) the double thickness is not objectionable. And the lap joint is generally self-supporting during the brazing process. Resting one flat member on the other is usually enough to maintain a uniform joint clearance. And, in tubular joints, nesting one tube inside the other holds them in proper alignment for brazing. However, suppose you want a joint that has the advantages of both types; single thickness at the joint combined with maximum tensile strength. You can get this combination by designing the joint as a butt-lap joint.



True, the butt-lap is usually a little more work to prepare than straight butt or lap, but the extra work can pay off. You wind up with a single thickness joint of maximum strength. And the joint is usually self-supporting when assembled for brazing.

Figuring the proper length of lap.

Obviously, you don't have to calculate the bonding area of a butt joint. It will be the cross-section of the thinner member and that's that. But lap joints are often variable. Their length can be increased or decreased. How long should a lap joint be? The rule of thumb is to design the lap joint to be three times as long as the thickness of the thinner joint member.



A longer lap may waste brazing filler metal and use more base metal material than is really needed, without a corresponding increase in joint strength. And a shorter lap will lower the strength of the joint. For most applications, you're on safe ground with the "rule of three." More specifically, if you know the approximate tensile strengths of the base members, the lop length required for optimum joint strength in a silver brazed joint is as follows:

Tensile strength of weakest member	Lap length = factor x W (W = thickness of weakest member)
35,000 psi - 241.3 MPa	2 x W
60,000 psi - 413.7 MPa	3 x W
100,000 psi - 689.5 MPa	5 x W
130,000 psi - 896.3 MPa	6 x W
175,000 psi -1,206.6 MPa	8 x W

NOTE: ksi x 6.8948 = 1 MPa

If you have great man identical assemblies to braze, or if the joint strength is critical, it will help to figure the length of lap more exactly, to gain maximum strength with minimum use of brazing materials, the formulas given below will help you calculate the optimum lap length for flat and for tubular joints.

Figuring length of lap for flat joints.

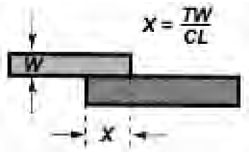
X = Length of lap

T = Tensile strength of weakest member

W = Thickness of weakest member

C = Joint integrity factor of .8

L = Shear strength of brazed filler metal



Let’s see how this formula works, using an example.

Problem: *What length of lap do you need to join .050" annealed Monel sheet to a metal of equal or greater strength?*

Solution:

C = .8 T = 70,000 psi (annealed Monel sheet)
W = .050"
L **=** 25,000 psi (Typical shear strength for silver brazing filler metals)
X = (70,000 x .050) /(.8 x 25,000) = .18" lap length

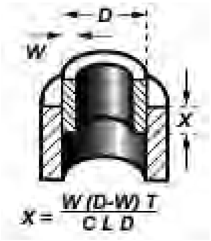
Problem in metric: *What length of lap do you need to join 1.27 mm annealed Monel sheet to a metal of equal or greater strengths*

Solution:

C = .8 T = 482.63 MPa (annealed Monel sheet)
W = 1.27 mm
L = 172.37 MPa (Typical shear strength for silver brazing filler metals)
X = (482.63 x 1.27) /(.8 x 172.37)
X = 4.5 mm (length of lap)

Figuring length of lap for tubular joints.

W (D-W) T CLD
X = Length of lap area
W = Wall thickness of weakest member
D = Diameter of lap area
T = Tensile strength of weakest member
C = Joint integrity factor of .8
L = Shear strength of brazed filler metal



Again, an example will serve to illustrate the use of this formula. Problem: *What length of lap do you need to join 3/4" O.D. copper tubing (wall thickness .064") to 3/4" I.D. steel tubing?*

Solution:

W = .064"
D = .750"
C= .8
T = 33,000 psi (annealed copper)
L **=** 25,000 psi (a typical value)
X = (.064 x (.75 – .064) x 33,000)/(.8 x .75 x 25,000)
X = .097" (length of lap)

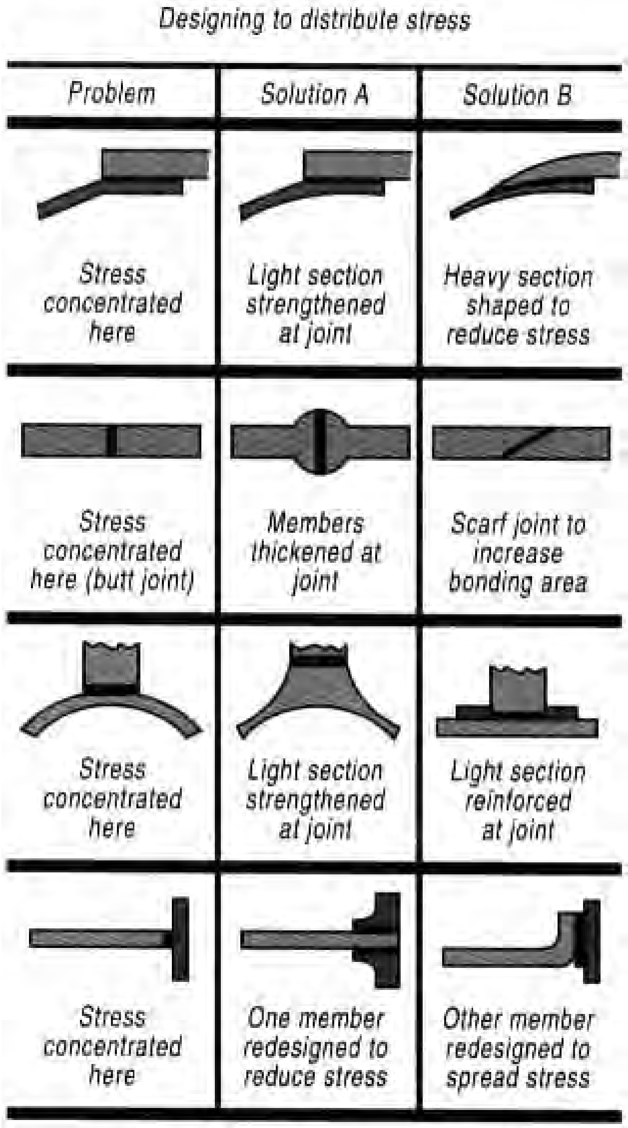
Problem in metric: *What length of lap do you need to join 19.05 mm O.D. copper tubing (wall thickness* 1.626 *mm] to 19.05 mm I.D. steel tubing?*

Solution:

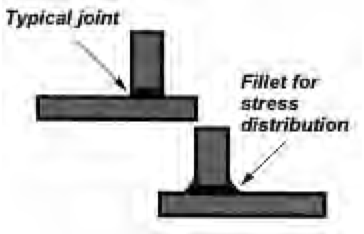
W = 1.626 mm
D = 19.05 mm
C = .8
T = 227.53 MPa (annealed copper)
L = 172.37 MPa (a typical value)
X = (1.626 x l19.05 - 1.626) x 227.53)/(.8 x 19.05 x 172.37)
X = 2.45 mm (length of lap)

Designing to distribute stress.

When you design a brazed joint, obviously you aim to provide at least minimum adequate strength for the given application. But in some joints, *maximum* mechanical strength may be your overriding concern. You can help insure this degree of strength by designing the joint to pre- vent concentration of stress from weakening the joint. Motto – *spread the stress.* Figure out where the greatest stress falls. Then impart flexibility to the heavier member at this point, or add strength to the weaker member. The illustrations below suggest a number of ways to spread the stress in a brazed joint.

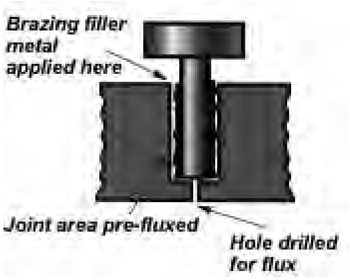


To sum it up – when you're designing a joint for maximum strength, use a lap or scarf design (to increase joint area) rather than a butt, and design the parts to prevent stress from being concentrated at a single point. There is one other technique for increasing the strength of a brazed joint, frequently effective in brazing small-part assemblies. You can create a stress-distribution *fillet,* simply by using a little more brazing filler metal than you normally would, or by using a more "sluggish" alloy. Usually you don't want or need a fillet in a brazed joint, as it doesn't add materially to joint strength. But where it contributes to spreading joint stresses, it pays to create the fillet.



Designing for service conditions.

In many brazed joints, the chief requirement is strength. And we've discussed various ways of achieving joint strength. But there are frequently other service requirements which may influence the joint design or filler metal selection. For example, you may be designing a brazed assembly that needs to be *electrically conductive.* A silver brazing filler metal, by virtue of its silver content, has very little tendency to increase electrical resistance across a properly-brazed joint. But you can further insure minimum resistance by using a close joint clearance, to keep the layer of filler metal as thin as possible. In addition, if strength is not a prime consideration, you can reduce length of lap. Instead of the customary "rule of three," you can reduce lap length to about 1-1/2 times the cross- section of the thinner member. If the brazed assembly has to be *pressure-tight* against gas or liquid, a lap joint is almost a must, since it with- stands greater pressure than a butt joint. And its broader bonding area reduces any chance of leakage. Another consideration in designing a joint to be leak proof is to vent the assembly. Providing a vent during the brazing process allows expanding air or gases to escape as the molten filler metal flows into the joint. Venting the assembly also prevents entrapment of flux in the joint. Avoiding entrapped gases or flux reduces the potential for leak paths. If possible, the assembly should be self-venting. Since flux is designed to be displaced by molten filler metal entering a joint, there should be no sharp corners or blind holes to cause flux entrapment. The joint should be designed so that the flux is pushed completely out of the joint by the filler metal. Where this is not possible, small holes may be drilled into the blind spots to allow flux escape. The joint is completed when molten filler metal appears at the outside surface of these drilled holes.



To maximize *corrosion-resistance* of a joint, select a brazing filler metal containing such elements as silver, gold or palladium, which are inherently corrosion-resistant. Keep joint clearances close and use a minimum amount of filler metal, so that the finished joint will expose only a fine line of brazing filler metal to the atmosphere. These are but a few examples of service requirements that may be demanded of your brazed assembly. As you can see both the joint design and filler metal selection must be considered. Fortunately, there are many filler metals and fluxes available to you – in a wide range of compositions, proper- ties and melting temperatures. The selector charts that appear later in this book can help you choose filler metals and fluxes that best meet the service requirements of the joints you design. The Technical Services Department at Handy & Harman/Lucas-Milhaupt is available to help answer any questions you may have with regard to your specific brazing application, joint design and/or filler metal selection.

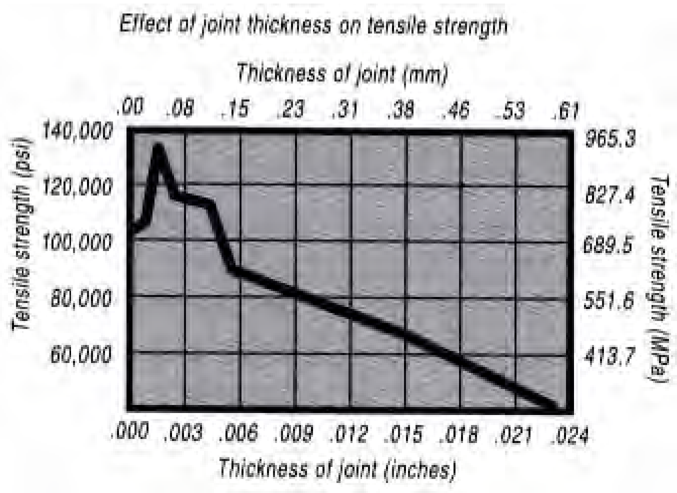
The six basic steps in brazing.

The importance of correct procedures.

We've said that a brazed joint "makes itself" – or that capillary action, more than operator skill, insures the distribution of the filler metal into the joint. The real skill lies in the design and engineering of the joint. But even a properly-designed joint can turn out imperfectly if correct brazing procedures are not followed. These procedures boil down to six basic steps. They are generally simple to perform (some may take only a few seconds), but none of them should be omitted from your brazing operation if you want to end up with sound, strong, neat-appearing joints. For the sake of simplicity, we'll discuss these six steps mainly in terms of "manual brazing," that is, brazing with hand-held torch and hand-fed filler metal. But everything said about manual brazing applies as well to mass production brazing. The same steps must be taken, although they may be performed in a different manner.

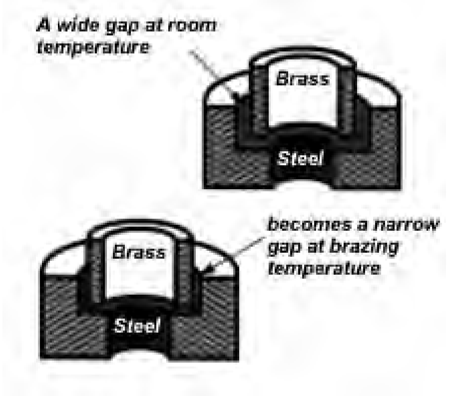
Step 1: Good fit and proper clearances.

Brazing, as we've seen, uses the principle of capillary action to distribute the molten filler metal between the surfaces of the base metals. Therefore, during the brazing operation, you should take care to maintain a clearance between the base metals to allow capillary action to work most effectively. This means, in almost all cases – a close clearance*.* The following chart is based on brazing butt joints of stainless steel, using Handy & Harman's Easy-Flo filler metal. It shows how the tensile strength of the brazed joint varies with the amount of clearance between the parts being joined.

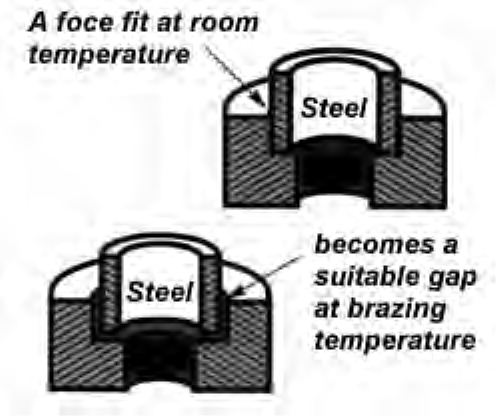


Note that the strongest joint (135,000 psi/930.8 MPa) is achieved when the joint clearance is .0015" (.038mm.) When the clearance is narrower than this, it's harder for the filler metal to distribute itself adequately throughout the entire joint – and joint strength is reduced. Conversely, if the gap is *wider* than necessary, the strength of the joint will be reduced almost to that of the filler metal itself. Also, capillary action is reduced, so the filler metal may fail to fill the joint completely – again lowering joint strength. So the ideal clearance for a brazed joint, in the example above, is in the neighborhood of .0015" (.038mm.) But in ordinary day-to-day brazing, you don't have to be this precise to get a sufficiently strong joint. Capillary action operates over a *range* of clearances, so you get a certain amount of leeway. Look at the chart again, and see that clearances ranging from .001" to .005" (.025 mm to .127 mm) still produce joints of 100,000 psi (689.5 MPa) tensile strength. Translated into everyday shop practice – an easy slip fit will give you a perfectly adequate brazed joint between two tubular parts. And if you're joining two flat parts, you can simply rest one on top of the other. The metal-to-metal contact is all the clearance you'll usually need, since the average "mill finish" of metals provides enough surface roughness to create capillary "paths" for the flow of molten filler metal. (Highly polished surfaces, on the other hand, tend to restrict filler metal flow.) However, there's a special factor you should consider carefully in planning your joint clearances. Brazed joints are made at *brazing* temperatures, not at room temperature.

So you must take into account the "coefficient of thermal expansion" of the metals being joined. This is particularly true of tubular assemblies in which dissimilar metals are joined. As an example, let's say you're brazing a brass bushing into a steel sleeve. Brass expands, when heated, more than steel. So if you machine the parts to have a room temperature clearance of .002"-.003" (.051 mm- .076 mm), by the time you've heated the parts to brazing temperatures the gap may have closed completely! The answer? Allow a greater *initial* clearance, so that the gap at brazing temperature will be about .002"-.003" (.051 mm-.076 mm.)



Of course, the same principle holds in reverse. If the outer part is brass and the inner part steel, you can start with virtually a light force fit at room temperature. By the time you reach brazing temperature, the more rapid expansion of the brass creates a suitable clearance.



How much allowance should you make for expansion and contraction? It depends on the nature and sizes of the metals being joined and the configuration of the joint itself. Although there are many variables involved in pin-pointing exact clearance tolerances for each situation, keep in mind the principle involved different metals expand at different rates when heated. To help you in planning proper clearances in brazing dissimilar metals, the chart on the opposite page furnishes the coefficient of thermal expansion for a variety of metals and alloys.

Step 2: Cleaning the metals.

Capillary action will work properly only when the surfaces of the metals are clean. If they are "contaminated" – coated with oil, grease, rust, scale or just plain dirt – those contaminants have to be removed. If they remain, they will form a barrier between the base metal surfaces and the brazing materials. An oily base metal, for example, will repel the flux, leaving bare spots that oxidize under heat and result in voids. Oil and grease will carbonize when heated, forming a film over which the filler metal will not flow. And brazing filler metal won't bond to a rusty surface. Cleaning the metal parts is seldom a complicated job, but it has to be done in the right sequence. Oil and grease should be removed first, because an acid pickle solution aimed to remove rust and scale won't work on a greasy surface. (If you try to remove rust or scale by abrasive cleaning, before getting rid of the oil, you'll wind up scrubbing the oil, as well as fine abrasive powder, more deeply into the surface.) Start by getting rid of oil and grease. In most cases you can do it very easily either by dipping the parts into a suitable degreasing solvent, by vapor degreasing, or by alkaline or aqueous cleaning. If the metal surfaces are coated with oxide or scale, you can remove those contaminants chemically or mechanically. For chemical removal, uses an acid pickle treatment, making sure that the chemicals are compatible with the base metals being cleaned, and that no acid traces remain in crevices or blind holes. Mechanical removal calls for abrasive cleaning. Particularly in repair brazing, where parts may be very dirty or heavily rusted, you can speed the cleaning process by using emery cloth, grinding wheel, or file or grit blast, followed by a rinsing operation. Once the parts are thoroughly clean, it's a good idea to flux and braze as soon as possible. That way, there's the least chance for recontamination of surfaces by factory dust or body oils deposited through handling.

Step 3: Fluxing the parts.

Flux is a chemical compound applied to the joint surfaces before brazing. Its use is essential in the brazing process (with a few exceptions noted later.) The reason? Heating a metal surface accelerates the formation of oxides, the result of chemical combination between the hot metal and oxygen in the air. These oxides must be prevented from forming or they'll inhibit the brazing filler metal from wetting and bonding to the surfaces. A coating of flux on the joint area, however, will shield the surfaces from the air, pre- venting oxide formation. And the flux will also dissolve and absorb any oxides that form during heating or that was not completely removed in the cleaning process. How *do you apply the flux to the joint?* Any way you can, as long as you cover the surfaces completely. Since flux is conventionally made in a paste consistency, it's usually most convenient to brush it on. But as production quantities increase, it may be more efficient to apply the flux by dip- ping – or dispensing a pre-measured deposit of high viscosity dispensable flux from an applicator gun. Why dispensable flux? Many companies find the repeatable deposit size improves joint consistency, and because typically less flux is used, the amount of residue entering the waste stream is also reduced.

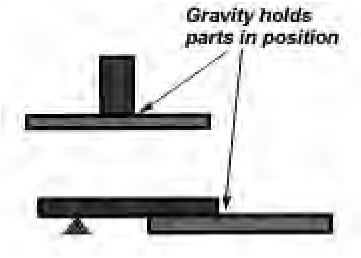
When do you flux? Typically just before brazing, if possible. That way the flux has least chance to dry out and flake off, or get knocked off the parts in handling. Which flux do you use? Choose the one formulated for the specific metals, temperatures and conditions of your brazing application. There are fluxes formulated for practically every need; for example – fluxes for brazing at very high temperatures (in the 2000°F/1093°C area), fluxes for metals with refractory oxides, fluxes for long heating cycles, and fluxes for dispensing by automated machines. Fortunately, your inventory problem is considerably simplified by the avail- ability of *general-purpose* fluxes, such as Handy & Harman's Handy Flux, which is suitable for most typical brazing jobs. (See page 40 for a chart of Handy & Harman/Lucas-Milhaupt fluxes.) Our technical representative can answer any questions you may have and assist you in your choice. *How much flux do you use?* Enough to last throughout the entire heating cycle. Keep in mind that the larger and heavier the pieces brazed, the longer the heating cycle will take – so use more flux. (Lighter pieces, of course, heat up taster and so require less flux.) As a general rule, *don't skimp on the flux.* It's your insurance against oxidation. Think of the flux as a sort of blotter. It absorbs oxides like a sponge absorbs water. An insufficient amount of flux will quickly become saturated and lose its effectiveness. A flux that absorbs less oxide not only insures a better joint than a totally saturated flux, but it is a lot easier to wash off after the brazed joint is completed. Flux can also act as a *temperature indicator,* minimizing the chance of overheating the parts. Handy & Harman's Handy Flux, for example, becomes completely clear and active at 1100°F/593°C. At this temperature, it looks like water and reveals the bright metal surface underneath – telling you that the base metal is just about hot enough to melt the brazing filler metal.

Temperature	**Appearance of flux**
212°F (100°C)	Water boils off.
600°F (315°C)	Flux becomes white and slightly puffy, and starts to "work."
800°F (435°C)	Flux lies against surface and has a milky appearance.
1100°F (593°C)	Flux is completely clear and active, looks like water. Bright metal surface is visible underneath, At this point, test the temperature be touching brazing filler metal to base metal, If brazing filler metal melts, assembly is at proper temperature for brazing.

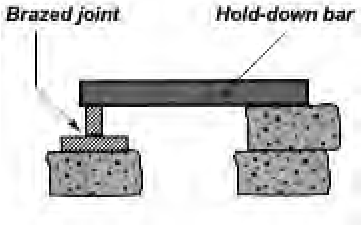
We've said that fluxing is an essential step in the brazing operation. This is generally true, yet there are a few exceptions to the rule. You can join copper to copper without flux, by using a brazing filler metal specially formulated for the job, such as Handy & Harman's Sil-Fos or Fos-Flo 7. (The phosphorus in these alloys acts as a fluxing agent on copper.) And you can often omit fluxing if you're going to braze the assembly in a controlled atmosphere. A controlled atmosphere is a gaseous mixture contained in an enclosed space, usually a brazing furnace. The atmosphere (such as hydrogen, nitrogen or dissociated ammonia) completely envelops the assemblies and, by excluding oxygen, prevents oxidation. Even in controlled atmosphere brazing, however you may find that a small amount of flux improves the wetting action of the brazing filler metal.

Step 4: Assembly for brazing.

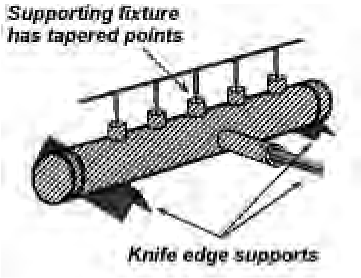
The parts of the assembly are cleaned and fluxed. Now you have to hold them in position for brazing. And you want to be sure they remain in correct alignment during the heating and cooling cycles, so that capillary action can do its job. If the shape and weight of the parts permit, the simplest way to hold them together is by gravity.



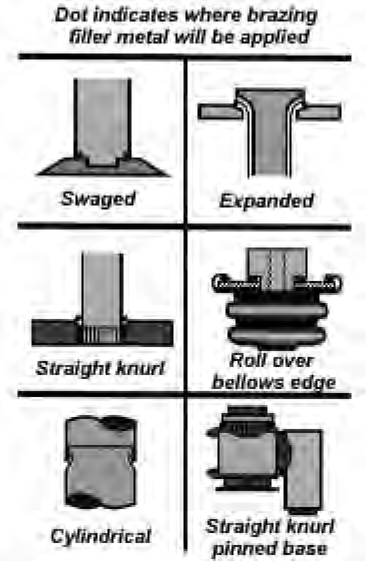
Or you can give gravity a helping hand by adding additional weight.



If you have a number of assemblies to braze and their configuration is too complex for self-support or clamping, it may be a good idea to use a brazing support fixture. In planning such a fixture, design it for the least possible mass and the least contact with the parts of the assembly. (A cumbersome fixture that contacts the assembly broadly will conduct heat away from the joint area.) Use *pin-point* and *knife-edge* design to reduce contact to the minimum.



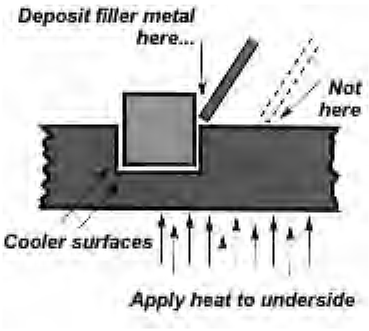
Try to use materials in your fixture that are poor heat conductors, such as stainless steel, Inconel or ceramics. Since these are poor conductors, they draw the least heat away from the joint. Choose materials with compatible expansion rates so you won’t get alterations in assembly alignment during the heating cycle. However, if you’re planning to braze hundreds of identical assemblies, then you should think in terms of designing the parts themselves for *self- support* during the brazing process. At the initial planning stage, design mechanical devices that will accomplish this purpose, and that can he incorporated in the fabricating operation. Typical devices include crimping, interlocking seams, swaging, peening, riveting, pinning, dimpling or knurling. Sharp corners should be minimized in these mechanically held assemblies, as such corners can impede capillary action. Corners should be slightly rounded to aid the flow of filler metal.



The *simplest* mechanical holding device is the best, since its only function is to hold the parts together while the permanent joint is made by brazing.

Step 5: Brazing the assembly.

The fifth step is the actual accomplishment of the brazing joint. It involves heating the assembly to brazing temperature, and flowing the filler metal through the joint. First, the heating process. As we've seen in brazing, you apply heat broadly to the base metals. If you're brazing a small assembly, you may heat the entire assembly to the flow point of the brazing filler metal. If you're brazing a large assembly, you heat a broad area around the joint. The heating method most commonly used in brazing a single assembly is the hand held torch. A variety of fuels are available – natural gas, acetylene, propane, propylene, etc., combusted with either oxygen or air. (Most popular is still the oxy/acetylene mixture.) All you have to keep in mind is that both metals in the assembly should be heated as uniformly as possible so they reach brazing temperature at the same time. When joining a heavy section to a thin section, the "splash-off" of the flame may be sufficient to heat the thin part. Keep the torch moving at all times and do not heat the braze area directly. When joining heavy sections, the flux may become transparent – which is at 1100°F (593°C) – before the full assembly is hot enough to receive the filler metal. Some metals are good conductors – and consequently carry off heat faster into cooler areas. Others are poor conductors and tend to retain heat and overheat readily. The good conductors will need more heat than the poor conductors, simply because they dissipate the heat more rapidly. In all cases, your best insurance against uneven heating is to keep a watchful eye on the flux. If the flux changes in appearance *uniformly,* the parts are being heated evenly, regard- less of the difference in their mass or conductivity. You've heated the assembly to brazing temperature. Now you are ready to deposit the filler metal. In manual brazing, all this involves is carefully holding the rod or wire against the joint area. The heated assembly will melt off a portion of the filler metal, which will instantly be drawn by capillary action throughout the entire joint area. You may want to add some flux to the end of the filler metal rod – about 2" to 3" (51 mm to 76 mm) – to improve the flow. This can be accomplished by either brushing on or dipping the rod in flux. On larger parts requiring longer heating time, or where the flux has become saturated with much oxide, the addition of fresh flux on the filler metal will improve the flow and penetration of the filler metal into the joint area. However, there is one small pre- caution to observe. Molten brazing filler metal tends to flow toward areas of higher temperature. In the heated assembly, the outer base metal surfaces may be slightly hotter than the interior joint surfaces. So take care to deposit the filler metal immediately adjacent to the joint.



If you deposit it away from the joint, it tends to plate over the hot surfaces rather than flow into the joint. In addition, it’s best to heat the side of the assembly opposite the point where you’re going to feed the filler metal. In the example above, you heat the underside of the larger plate, so that the heat draws the filler metal down fully into the joint. (Always remember – the filler metal tends to flow toward the source of heat.) And if you’re using performs – slugs, washers, shims or special shapes of filler metal – preplaced them at the joint area *before* you heat the assembly.

Step 6: Cleaning the brazed joint.

After you’ve brazed the assembly, you have to clean it. And cleaning is usually a two-step operation. First – removal of the flux residues. Second – pickling to remove any oxide scale formed during the brazing process. Flux removal is a simple, but essential operation. (Flux residues are chemically corrosive and, if not removed, could weaken certain joints.) Since most brazing fluxes are water soluble, the easiest way to remove them is to quench the assembly in hot water (120°F/50°C or hotter). Best bet is to immerse them while they’re still hot, just making sure that the filler metal has solidified completely before quenching. The glass-like flux residues will usually crack and flake off. If they’re a little stubborn, brush them lightly with a wire brush while the assembly is still in the hot water. You can use more elaborate methods of removing flux as well – an ultra- sonic cleaning tank to speed the action of the hot water, or live steam.

Two tables here somehow

The only time you run into trouble removing flux is when you haven’t used *enough* of it to begin with, or you’ve overheated the parts during the brazing process. Then the flux becomes totally saturated with oxides, usually turning green or black. In this case, the flux has to be removed by a mild acid solution. A 25% hydrochloric acid bath (heated to 140- 160°F/60-70°C) will usually dissolve the most stubborn flux residues. Simply agitate the brazed assembly in this solution for 30 seconds to 2 minutes. No need to brush. A word of caution, however – *acid solutions are potent, so when quenching hot brazed assemblies in an acid bath, be sure to wear a face shield and gloves.* After you’ve gotten rid of the flux, use a pickling solution to remove any oxides that remain on areas that were unprotected by flux during the brazing process. The best pickle to use is generally the one recommended by the manufacturer of the brazing materials you’re using. (See the Handy & Harman recommendations for pickling solutions on the opposite page.) Highly oxidizing pickling solutions, such as bright dips containing nitric acid, should be avoided if possible, as they attack the silver filler metal. If you do find it necessary to use them, keep the pickling time very short. Once the flux and oxides are removed from the brazed assembly, further finishing operations are seldom needed. The assembly is ready for use, or for the application of an electroplated finish. In the few instances where you need an ultra-clean finish, you can get it by polishing the assembly with a fine emery cloth. If the assemblies are going to be stored for use at a later time, give them a light rust-resistant protective coating by adding water soluble oil to the final rinse water.

Basic steps in brazing

1. Ensure fit and clearance
2. Clean metal
3. Flux prior to brazing
4. Fixturing of parts
5. Brazing the assembly
6. Cleaning the new joint

Hidden treasure in your scrap.

There's one last thing you should take into account, as part of your cleaning and finishing operations – the possible salvage value of your brazing scrap. Brazing filler metals may contain silver, often in fairly high proportions. So does the filler metal scrap? And that silver is reclaimable at a good price. It's hard to believe that the amount of scrap you generate in your brazing operation is large enough to warrant salvaging. But consider this true story ... A Handy & Harman brazing representative, inquiring about scrap salvage, was told by a plant superintendent, "We don't *have* any brazing scrap. We tack the rod stubs and coil ends together and use them up." The representative, however, noticed some brazing filler metal drip- pings hanging from the fixtures of a conveyorized brazing operation. He took a couple of samples for lab analysis. Some weeks later he presented the superintendent with a bright disc of pure silver. The silver had been refined from those few "worthless" drippings. From then on, those conveyor fixtures were cleaned regularly – and every bit of scrap accumulated for its silver value. Conveyor fixture drippings are just one source of reclaimable silver. There are others. For example, sup- pose you're hand-cutting brazing filler metal strip to make custom-shaped shims for brazing carbide tool tips. The leftover scrap has just as high a silver content as the brazing shim itself. Depending on the nature of your brazing operations, there's always the possibility that you're generating enough scrap to make accumulation of it over a period of time very worth- while. The fact is – the refining of brazing filler metal scrap can often substantially reduce the cost of brazing operations. Your Handy & Harman/ Lucas-Milhaupt representative can help you spot the "hidden treasure" in your operation and implement the best salvage procedures.

Balancing the picture.

We've discussed the six basic steps required in correct brazing procedures. And we've gone into a fair amount of detail in order to be as informative as possible. To get a more balanced picture of the overall brazing process, it's important to note that in most day-to-day brazing work, these steps are accomplished very rapidly. Take the cleaning process, for example. Newly-fabricated metal parts may need no cleaning at all. When they do, a quick dip, dozens at a time, in a degreasing solution does the job. Fluxing is usually no more than a fast dab of a brush or dipping ends of the parts in flux. Heating can often be accomplished in seconds with an oxy-acetylene torch. And flowing the filler metal is virtually instantaneous, thanks to capillary action. Finally, flux removal is generally no more than a hot water rinse, and oxide removal needs only a dip into an acid bath. There are exceptions to the rule, of course, but in most cases a brazed joint is made fast – considerably faster than a linear welded joint. And, as we'll see later on, these economies in time and labor is multiplied many times over in high production automated brazing. The pure *speed of brazing* represents one of its most significant advantages as a metal joining process

Safety in Brazing

In brazing, there is always the possibility of dangerous fumes and gases rising from base metal coatings, ink and cadmium-bearing filler metals, and from fluorides in fluxes. The following well-tested precautions should be followed to guard against any hazard from these fumes.

1. Ventilate confined areas. Use ventilating fans and exhaust hoods to carry all fumes and gases away from work, and air supplied respirators as required.
2. Clean base metals thoroughly, a surface contaminant of unknown composition on base metals may add to fume hazard and may cause a too rapid breakdown of flux, leading to overheating.
3. Use sufficient flux. Flux protects base metals and filler metal during heating cycle. Full flux coverage reduces fuming; also, consult your MSDS regarding specific hazards associated with brazing flux.
4. Heat metals broadly. Heat the base metals broadly and uniformly. Intense localized heating uses up flux, increases danger of fuming.
5. Know you base metals. A cadmium coating on a base metal volatilizes and produce toxic fume during heating. Zinc coatings (galvanized) will also fume when heated. Learn to recognize these coatings. It is recommended that they be removed before parts are heated for brazing.
6. Know you fill metals. Be especially careful not to overheat assembly when using filler metals that contain cadmium. Consult the Material Safety Data Sheet for maximum recommended brazing temperatures of a specific filler metal. The filler metal carries a warning label. Be sure to look for it and follow the instructions.

(For safety considerations, see the American National Standard Z49.1, "Safety in Welding and Cutting"; published be the American Welding Society (AWS), 550 N.W. LeJeune Rd., Miami, Florida 33126.

Recommended pickling solutions for post-braze removal of oxides

The pickling solutions recommended below may be used to remove oxides from areas that were not protected by flux during the brazing process. In general, they should be used after the flux residue has been removed from the brazed assembly.

Application	Formulation	Comments
Oxide removal from copper, brass, bronze, nickel silver and other copper alloys containing high percentages of copper.	10 to 25% hot sulphuric acid with 5 to 10% potassium dichromate added.	Pickling can be done at same time flux is removed. Will work on carbon steels, but if pickle is contaminated with copper, the copper will plate out on the steel and will have to be removed mechanically. This sulphuric pickle will remove copper or cuprous oxide stains from copper alloys. It is an oxidizing pickle, and will discolor the silver filler metal, leaving it a dull gray.
Oxide removal from irons and steels.	A 50% hydrochloric acid solution, used cold or warm, More diluted acid can be used (10 to 25%) at higher temperatures (140-160°F/60-70°C.)	A mixture of 1 part hydrochloric acid to 2 parts water can be used for Monel and other high nickel alloys. Pickling solution should be heated to about 180'F/80'C. Mechanical finishing is necessary for bright finishes. This HCI pickle is *not* like bright dips on nonferrous metals.
Oxide removal stainless steels and alloys containing chromium.	20% sulphuric acid, 20% hydrochloric acid, 60% water, used at a temperature of 170-180°F(75-80°C.)	This pickle is followed directly by a 10% nitric dip, and then a clean water rinse.
	20% hydrochloric acid, 10% nitric acid, 70% water, used at about 150°F(65°C.)	This pickle is more aggressive than the sulphuric-hydrochloric mixture listed above, and will etch both the steel and the filler metal.

Note: The pickles recommended above will work with any of the standard silver filler metals, and no specific instructions are required for the individual filler metals. The phos-copper and silver-bearing phos-copper filler metals are different, and then only when used on copper without flux. In this case, a hard copper phosphate slag forms in small globules on the metal surface. Prolonged pickling in sulphuric acid will remove this slag, but a short pickle in 50% hydrochloric acid for a few minutes is more effective. When the brazed joint is to be plated or tinned, the removal of the slag is absolutely essential. A final mechanical cleaning, therefore, is advisable for work which is to be plated.

Section 2

Case studies of brazing applications.

In this section, we move from the theoretical to the practical.

On the following pages, we discuss a number of current brazing applications, all of them using Handy & Harman/Lucas-Milhaupt brazing materials. In each case, we describe and picture the application and explain why brazing was chosen as the preferred joining method.

Even this relatively limited number of examples furnishes a good idea of the immense flexibility of the brazing process.

The examples illustrate a wide range of sizes and types in brazed assemblies from fine wire sunglass frames to industrial air conditioning coils.

They show how a great variety of dissimilar metals, both ferrous and nonferrous, are joined into single assemblies.

There are examples of different types of heating methods and production techniques ranging from simple torch brazing to fully automatic processes using Lucas-Milhaupt equipment.

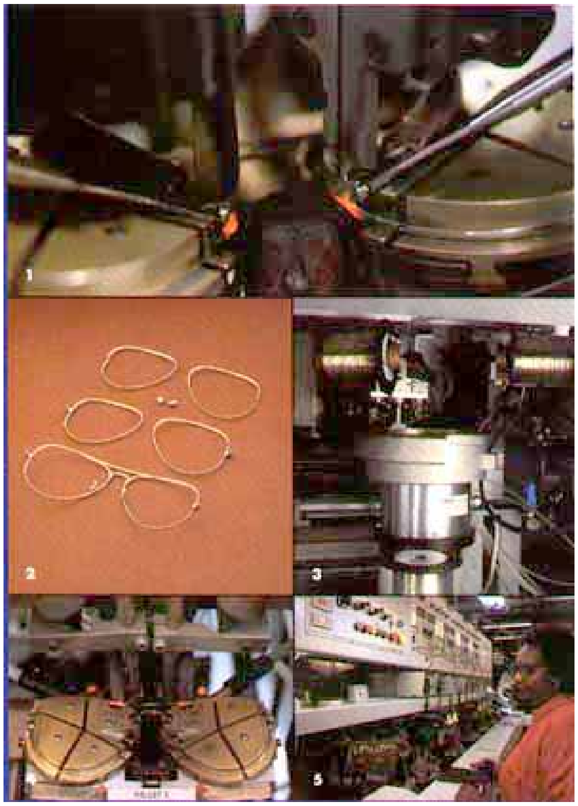
And the case studies help illustrate the many forms of filler metal options used in modern brazing including paste, foil, rings and stock and custom pre-forms.

We hope these examples will help stimulate your thinking about new possibilities for brazing in your own manufacturing operation. They may also suggest procedures, equipment and techniques that will help you braze more efficiently.

When Appearance is Critical, Think Brazing.

Application:

Wire frame sunglasses, manufactured by Bausch *8* Lomb, Co., in Rochester, N.Y. Bausch *&* Lomb uses the brazing process to produce the ten joints needed for the Ray-8an wire frames available in its sunglasses product line. The component metal parts of frame fronts, which consist of an eye wire, end pieces, a bridge, a brace and a brow bar, are constructed of nickel or a nickel alloy. To form the sunglass front, they are joined together by induction brazing in a series of steps. At each step of the process, they are held in place by a jig. The Handy & Harman / Lucas - Milhaupt brazing filler metals typically used for the joints are 50% silver - bearing alloys such as Braze 505. In some instances, Handy Flux or Handy Flux Type 8-1 is used to insure optimal wetting action. When the brazing process is complete, the fronts are pickled to remove any discoloration, polished, and then plated in the desired color. The brazed joints in the finished frames are virtually invisible to the eye.



1. The bridge of a sunglass frame is brazed.
2. Various metal frame parts are joined during the induction brazing process.
3. Handy & Harman/Lucas-Milhaupt filler metal in wire from is used.
4. Brazing provides invisible joints as this brow bar is brazed.
5. A total of 10 joints are formed during the fully automated process.

Why brazing?

When people buy sunglasses, appearance is key in their selection process. Brazing's ability to produce invisible joints makes it the only logical choice in metal joining options for the Bausch *8* Lomb line. Plus, the strength and durability of brazed joints help insure the sunglass frames hold up to the rigors of regular use**.**

Brazing Provides Leak-Free Passage For Vehicle Fuel.

Application:

Fuel senders used in vehicles manufactured by Ford Motor Company. Ford Motor Company relies on brazing in several phases of vehicle manufacture. In the assembly of its fuel pump systems, brazing helps provide a leak free route for gasoline to be transported to the engine. Specifically, brazing is used to construct the fuel sender, a part that mounts directly onto a vehicle's gas tank. With a fuel pump attached to it, the fuel sender pulls gas out of the tank and sends it through tubes to the fuel injection system. In the manufacture of the fuel sender, two stainless steel arched tubes are brazed through a round stainless flange. The tubes fit neatly between the two existing holes in the flange. An operator manually snaps a C-shaped arc of filler metal, (Lucas-Milhaupt's CDA-521), into the gap between each tube and the flange. The parts are then placed on a belt and sent through an oxygen-free, controlled-atmosphere furnace. The absence of oxygen eliminates the need for flux or cleaning, and the brazed parts emerge shiny and clean. Following this rapid metal joining process, each fuel sender is 100**%** leak tested.

1. Teams of Ford employees place the stainless tubes in place in the flange.
2. Filler metal arcs are manually positioned to fill the gap between each tube and the flange hole.
3. Assembled parts are placed on a conveyor for brazing
4. Finished fuel senders are leak tested

Why brazing?

At Ford, Quality is Job l. That's why the automaker relies on brazing to construct its fuel senders. The operation itself is simple and cost-efficient, and the brazed parts are leak-free and attractive to the eye.

Automated Soldering of Ice Tray Assemblies is a Cool Process.

Application:

Ice trays used in large, industrial ice cube machines manufactured by IMI Cornelius of Mason City, Iowa.

The soldering story: Hotels, motels, restaurants, and other commercial and industrial businesses look to IMI Cornelius to make sure they never run out of ice. IMI Cornelius looks to Lucas-Milhaupt products to ensure the ice cube trays inside their equipment consistently deliver the cold goods. In the tray assembly process, a metal grid used to form the actual cubes is joined to the inside of the tray, and a serpentine coil that delivers coolant to the grid is joined to the tray back. Soldering is the metal joining method used for both steps which are performed simultaneously. To join the metal grids to the tray, IMI uses tin silver solder paste filler metal, a step-saving product that includes flux. A tin silver foil is used to join the coil to the tray back. Lucas-Milhaupt provides the foil in sheets cut to match the width of the trays, and IMI trims to the desired length. An operator-controlled process applies both the paste between the metal grid and the tray, and the foil strips and flux between the tray and the coil. The tray then moves on a conveyor into the furnace for the soldering process.

1. The completed ice cube tray parts.
2. A coating of filler metal paste is applied to the tray.
3. The tray is positioned on the pre-cut and trimmed foil.
4. The coils prior to soldering.
5. An operator positions the ice cube tray parts on a conveyor for soldering.

Why soldering?

IMI Cornelius relies on soldering to produce a strong, consistent and cost-effective assembly in its plated ice cube trays. The process used is identical to brazing with the only difference being the use of a lower melt temperature (under 840’F).

Automated Brazing of Aluminum Tubing

Application:

Tubing assemblies for air conditioning components produced by ITT Automotive.

The brazing story.

ITT Automotive, a leading supplier to major automakers, manufactures aluminum tubing assemblies for vehicle air conditioning components. The company makes both inlet and outlet tubes for condensers and evaporators and a tube header for air conditioning condensers.

ITT relies on brazing in a variety of different processes throughout its facility; from 2-piece assemblies to the more complex tube headers requiring up to seven brazing operations. Most involve the joining of aluminum components using paste, flux and/or pre-forms.

All ITT’s brazing operations are semi-automated. Aluminum tubing is joined at multi-station index tables. Steps in the process include loading the parts, application of filler metal, heating, cooling and cleaning.

1. Inlet and outlet tubes are brazed at an automated index table.
2. Brazing in action.
3. Aluminum paste or flux is dispensed in pre-measured amounts.
4. One of several semi-automated systems at ITT

Why brazing?

ITT’s automotive customers, looking for a high quality, cost effective part, specify that brazing be used in the production of their tubing assemblies. In this application, brazing is the logical choice as it provides a dependable, strong joint at the most economical cost.

Brazed metal chairs stand up to close inspection.

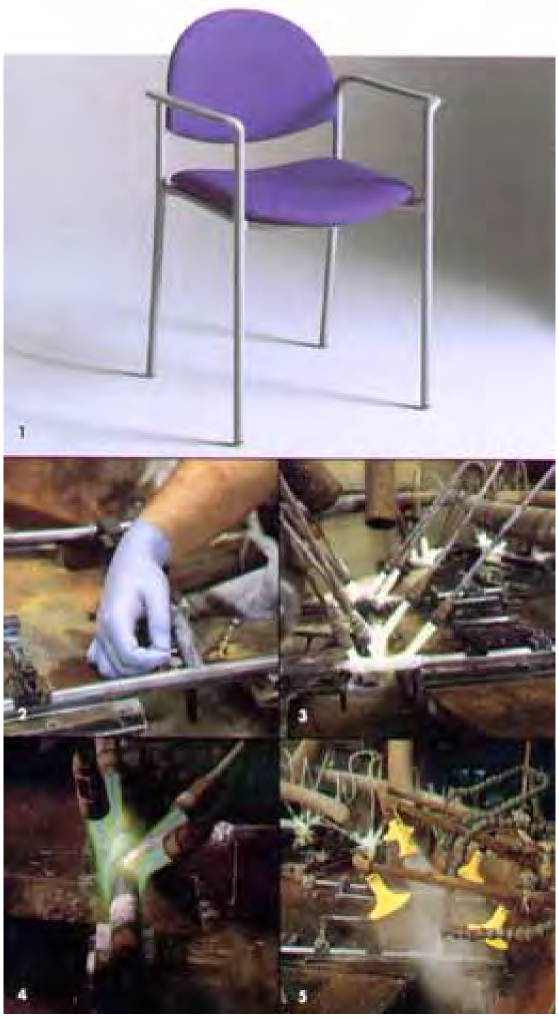
Application:

Metal frame chairs and other furniture manufactured by Kl (Krueger International), of Green Bay, Wl.

In 1941, Kl introduced its initial product, a steel folding chair, and today markets an extensive line of seating, tables and other furnishings. The company relies on brazing and Handy & Harman filler metals to ensure smooth, strong and invisible joints in the metal frames of its products.

Brazing is used in a variety of products at Kl, and is a critical step in the manufacture of the company’s high volume, Versa brand chairs. The metal framed product line ranges from individual chairs with poly, wood or fabric seats to tandem seating units and children’s furniture.

Although the number of brazed joints per piece may vary, in most cases the joints are formed where the metal seat base and leg pieces come together. In all cases, like metals are joined, usually steel to steel. The brazing process takes place at an index station where multiple frames are joined simultaneously. An operator manually positions a ring or slug (Braze 505), in position on the frame parts. Flux is applied, and the parts are rapidly heated using gas-air torches. Once brazed, the finished frame is cooled using forced air and then water quenched to clean.



1. KI on brazing to ensure appearance and strength in its Versa chairs.
2. A technician positions the filler metal.
3. Pre-heating of joints.
4. Final heating station, where joints are completed.
5. Water quenching helps to clean the brazed metal frames.

Why brazing?

Brazing is the only choice when appearance and strength are critical. By brazing the metal frames on its Versa chairs, Kl is ensured of not only strength and durability in its joints, but also a consistently smooth, clean and beautiful joint.

Brazing Boosts Appearance and Strength of Pressurized Sprayers.

Application:

Pressurized sprayers manufactured by Milwaukee Sprayer Mfg. Co., Inc, in Milwaukee, Wl

The brazing story:

In the manufacture of its pressurized sprayers, Milwaukee Sprayer relies on the brazing process to join brass to brass and form three separate joints. Using a torch to heat, an operator brazes inlet and outlet adapters onto the top of the brass sprayer shell. Two distinct joints are made. The third joint is formed when the bottom portion of the sprayer is joined to the shell. This process is semi-automatic and occurs as the part is rotated in an automated flame brazier.

To produce the strong brazed joints, Milwaukee Sprayer uses Lucas Milhaupt’s Braze 380 and 505 special-purpose alloys, all in ring form. Prior to brazing, the parts are coated with Handy-Flux to prevent oxide formation during heating. Once the joints are formed, the parts are air cooled, quenched in hot water and cleaned. In total, the entire brazing process is completed in about 45 seconds. The finished pressurized sprayer is strong and leak-tight.

1. Brazing produces virtually invisible joints for optimum appearance.
2. Three joints are brazed in the can assembly.
3. An application of flux prevents oxide formation during heating.
4. Using an automated flame brazier, the can bottom is joined to the shell.
5. The finished parts are quenched in hot water and cleaned.

Why brazing?

Brazing is the optimum choice to produce an attractive pressurized spray can. With all brass to brass connections visible to the eye, brazing's invisible joints help ensure the very best product appearance. Along with this aesthetic benefit, the process guarantees joints that are strong and durable.

Flexibility of Brazing Ideal for Copper Coil Automation.

Application:

Copper coils for central air conditioners manufactured by The Trane Company, a division of American Standard in Trenton, N.J.

The Brazing story:

The Trane Company relies on a combination of manual and automated brazing processes in the manufacture of its air conditioning units.

In Trane's production of evaporator coils for air conditioning units, an automated brazing system supplied by Lucas-Milhaupt is used. Called the "COBRA" (COil BRAzer), this sophisticated in-line system joins copper return bends to copper tubes at a highly advanced and rapid rate. As designed, the COBRA system has the capacity to braze various sized one to three row coils at rates as high as 40,000 joints per hour.

1. The COBRA, supplied by Luca-Milhaupt, is a sophisticated in-line system that brazes at a highly advanced and rapid rate.
2. Cross firing spear flame burners braze the return bends in place.
3. Finished evaporator and condenser coils are tested prior to assembly in air conditioning unit.

The COBRA system, which is manually loaded, conveys the coils between cross firing spear flame burners that supply the heat to braze the return bends in place. A phos copper alloy in ring form is used. When used on copper, this alloy is self-fluxing. They are then cooled to room temperature before being off-loaded to another conveyor for final testing and assembly into air conditioning units.

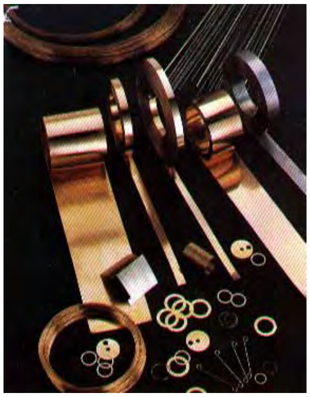
Why brazing?

In the coil brazing process, an abundance of joints are formed on a continuous basis. In a year, the Trane Company brazes about 30 million joints. Brazing, which is highly flexible and a process ideally suited for advanced levels of automation, is a logical choice for this application.

Products to meet your brazing needs.

Handy & Harman/ Lucas-Milhaupt offer you the widest assortment of filler metals in the industry allowing you to select the most efficient alloy for your assembly and process. Our general purpose filler metal inventory is extensive including Easy-FLo alloys and cadmium free alternatives.

When Specialty alloys are needed, we offer a variety of gold alloys, vacuum grade filler metals, Hi-Temp alloys, copper filler metals, aluminum alloys and sort solders.



An assortment of copper-phosphorous filler metals including Sil-Fos and Fos Flo alloys are available.

Brazing in Action

Off-the-shelf or custom-made, Handy & Harman/Lucas-Milhaupt can provide you with the most efficient, reliable and cost effective filler metal forms. Options include foil, paste pre-forms, rings, strip and wire.

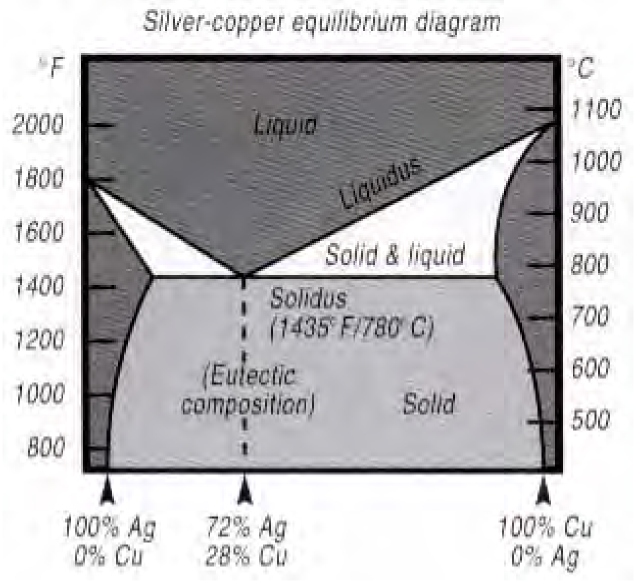
As flux is often critical to the brazing and soldering process, we offer a wide variety of flux products, this includes the Handy Flux line of general purpose and specialty fluxes which have been the standard in the industry for well over 50 years**.**

Selecting your brazing materials.

Before choosing a filler metal, you must understand and evaluate the three basic characteristics of filler metals: *physical properties melting behavior* and *forms available.* Let's look at each of these characteristics.

Physical properties and melting behavior.

The *physical properties* of a filler metal are based on metallurgical composition. (Brazing filler metals are invariably alloys, made of two or more "pure" metals.) This composition determines whether the filler metal is compatible with the metals being joined – capable of wetting them and flowing completely through the joint area without forming detrimental metallurgical compounds. Plus, special service or production requirements may call for special properties. For example, if you're brazing in a vacuum, you need a filler metal free of any volatile elements, such as cadmium or zinc. Some electronic components require filler metals of very high purity. And corrosion-resistant joints need filler metals that are both corrosion- resistant and compatible with the base metals being joined. *Melting behavior* is also based on metallurgical composition. Since most filler metals are alloys, they usually do not melt the same as pure metals which change from a solid to a liquid state at one temperature. However, there is an important exception to this statement. There is a class of alloys, termed "eutectics," that *do* melt in the same manner as pure metals. An example of a eutectic composition is Handy *8* Harman's Braze 721, a simple silver-copper alloy made of 72% silver and 28% copper. This filler metal melts completely at a single temperature – 1435°F (780°C). In metallurgical terms, its melting point (solidus) and flow point (liquidus) are identical. This *melting behavior* is shown on the following chart. Note that at the 72% silver, 28% copper composition, liquidus and solidus temperatures are the same.



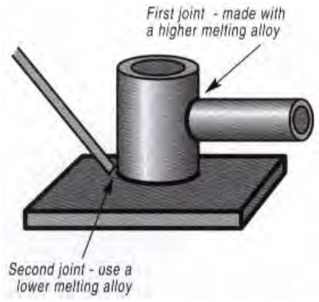
And, the alloys to the left or right of this eutectic composition do not go directly from a solid to a liquid state, but pass through a "mushy" *range* where the alloy is both solid and liquid. This range is the difference between the "solidus" temperature, which is the highest temperature at which the alloy is completely solid (i.e., the point where melting starts when the alloy is heated) and the "liquidus" temperature, which is the lowest temperature at which the alloy is completely liquid (i.e., the point where solidifying starts as the alloy is cooled.)

Importance of "melting range."

Look at a couple of examples. If you are brazing an assembly with a narrow, closely controlled clearance, Handy & Harman’s Braze 560 filler metal works weII. This cadmium free alloy begins to melt at 1145°F/620°C and flows freely at 1205°F/650°C. Its melting range is 60°F/ 15°C. When brazing an assembly with wide clearances (greater than .005), select a filler metal like the cadmium free Braze 380. As it starts to melt at I 200°F/650°C and becomes fully liquid at 1330°F/720°C, its flow characteristics are sluggish enough to fill wide gaps.

Consider the "liquidus temperature."

In all brazing applications, the *"liquidus temperature"* of the brazing filler metal is a critical factor. Since in brazing you never want – or need – to melt the base metals, you should select a filler metal whose liquidus temperature is lower than the solidus temperature of both of the base metals being joined. There are several brazing situations in which the liquidus temperature factor calls for special consideration. For example, when "step brazing" an assembly – that is, brazing in the vicinity of a previously brazed joint, you don’t want the second brazing operation to disturb the first joint. The way to prevent this is to use more than one type of filler metal. Make the second joint with a filler metal *lower in liquidus temperature* than that used for the first joint. This way you are assured the first joint will not be re- melted when making the second. Also consider liquidus temperature when brazing assemblies that must be heat treated. In these instances, you have two options. You can heat treat and then braze – in which case you should select a filler metal whose liquidus temperature is lower than the heat-treating temperature. This way the hardness properties won't be adversely affected by brazing. Or you can heat treat and braze simultaneously. In this case, the liquidus temperature of the filler metal should be closely equivalent to the heat treating temperatures .



Brazing temperature.

In most cases, the brazing temperature will be above the liquidus temperature of the filler metal and below the solidus temperature of the metal being joined. The actual brazing temperature will depend on factors such as the rate of heating, the type of filler metal flow required, the melt range of the filler metal and any elements in the filler metal that may inhibit flow. In general, rapid heating and the use of eutectic compositions or alloys with small melt ranges will allow you to braze at a lower temperature. There are a few filler metals which will flow acceptably below their liquidus temperatures. These are the Fos Flo and Sil-Fos filler metals.

Forms of filler metal.

Finally, in selecting a brazing filler metal, consider the *forms* in which it is available; as coils or spools of wire, lengths of rod, strip, powder, paste and pre-forms (including flux coated products). In maintenance brazing, single assembly brazing or short-run production, the manual torch, with wire or rod fed by hand, remains the most widely used method. Per-forms and pastes are used frequently in production brazing. Evaluate your needs and select the form that provides the best results and most efficient use of material. The information at right should help you in your selection.

How much filler metal to use.

Once you've carefully determined the best filler metal for the job, you need to figure out how much filler metal is needed for the joint. When brazing a single assembly, this is seldom a problem. You touch the brazing rod to the heated joint area, a portion of the rod melts and capillary action draws it through the joint. When you remove the rod from the joint, you can see the fine line of filler metal running all around the joint edge. No calculation is needed. When in doubt during maintenance brazing or in short-run production, the rule of thumb is to use *more* rather than *less* filler metal. Joint soundness is your primary goal, so it's best to use a little extra filler metal to insure that soundness. In high production brazing, how- ever, particularly where you're pre- lacing or automatically feeding the filler metal, unnecessary use of filler metal can be costly. Here you want to calculate the amount of filler metal as precisely as possible, so you make sound joints with *minimum* usage of materials. To accomplish this, calculate the volume of the joint (at the brazing temperature), adding 10-25% for fillet and shrinkage, and then supply the equivalent volume of filler metal.

Using the Selection Charts.

One final word on filler metal selection – manufacturers' selection charts can make your job easy. Make use of them and you won't have to be a graduate metallurgical engineer to pick the right filler metal for your brazing application. For example, the chart on pages 34-37 guides you to the right Handy &, Harman/Lucas-Milhaupt filler metal with little difficulty. Let's look closer at this chart. Note that a relatively few "general purpose" alloys can cover over 90% of your brazing needs. And for specialized applications, you can readily deter- mine the "special purpose" alloy best suited to the job. The chart also includes all the information you need on the melting range and metallurgical composition of each filler metal. It's important to remember that every brazing and soldering application has requirements which may make one filler metal alloy and form more appropriate and cost effective than another. When you need assistance, let our technical experts evaluate your unique needs and give you a completely objective recommendation.

Selecting a filler metal form.

Filler metals for brazing applications are available in numerous forms.

Powders - Filler metal powders are produced in a range of particle sizes. Although the standard is - 100 mesh (- 150 microns), other sizes can be produced to meet specialized needs. Prior to brazing, most powders are turned into a past form; however there are some applications where powder is used directly. The distinct advantage of a powder form is the wide spectrum of available alloys. A variety of alloys can be produced in powder form but because of their unique characteristics cannot be made into wrought form of preform parts.

Paste - Brazing paste is produced by combining one or more parts of a filler metal, flux and a binder component. It comes in a consistency of caulking compound and can be easily dispensed making it ideally suited for manual applications and cost-saving automation. Using dispensing equipment, the desired quantity of paste can be placed directly, in a variety of configurations, on the joint to be brazed. Paste, like powders, offers a much wider choice of alloys. Paste can also be tailored to meet special application needs by varying the ingredients. Finally sense flux may already be formulated into the product; the extra step to apply flux is eliminated.

Wire, Rods and Strips - Coils or spools of wire, lengths of rod and filler metal strips work well en maintenance brazing, one-assembly-at-a-time brazing or short-run production where the wire or rod is fed be hand, These traditional forms of filler metal are available in stock sizes or, upon request, can be modified to custom widths and thicknesses to provide the best use of material. In automated production, rods and strips are typically not the best option.

Pre-forms - Filler metal pre-forms are manufactured by forming bulk wire and strip into special shapes can be produced, from simple to intricate, to best meet the needs of each application. There are many advantages to pre-forms. Because pre-forms permit alloy pre-placement, they are highly adaptable to automation. Automation increases overall production rate and allows the use of unskilled labor; both of which save time and money. Pre-forms also help minimize and standardize costs. Hand feeding filler metal may use up to 50% more alloy than actually necessary. Pre-forms are measured amounts of alloy ensuring the exact volume required is used every time. Aesthetically, pre-forms help improve a part's appearance. Pre-forms are designed to surround the joint providing a smooth look with only a thin line of alloy visible. Since the correct amount of alloy fills the joint area, this usually results in a reduction of rejected parts.

Flux-Coated Forms - Some filler metal forms are available with a flux-coating. The advantage to these types of forms is that the final fluxing step is eliminated. The final cleaning step is easier as well with less contaminants going out with the rinsing water.

Let the Weld Guru guide you through the world of Cast Iron welding

Cast iron is an alloy of iron, carbon, and silicon, in which the amount of carbon is usually more than 1.7 percent and less than 4.5 percent.

(1) The most widely used type is known as gray iron. Gray iron has a variety of compositions, but is usually such that it is primarily perlite with many graphite flakes dispersed throughout.

Braze Cast Iron !! See it done !!

(2) There are also alloy cast irons which contain small amounts of chromium, nickel, molybdenum, copper, or other elements added to provide specific properties.

(3) Another alloy iron is austenitic cast iron, which is modified by additions of nickel and other elements to reduce the transformation temperature so that the structure is austenitic at room or normal temperatures. Austenitic cast irons have a high degree of corrosion resistance.

(4) In white cast , almost all the carbon is in the combined form. This provides a cast iron with higher hardness, which is used for abrasion resistance.

(5) Malleable cast is made by giving white cast a special annealing heat treatment to change the structure of the carbon in the iron. The structure is changed to perlitic or ferritic, which increases its ductility.

(6) Nodular iron and ductile cast iron are made by the addition of magnesium or aluminum which will either tie up the carbon in a combined state or will give the free carbon a spherical or nodular shape, rather than the normal flake shape in gray cast iron. This structure provides a greater degree of ductility or malleability of the casting.

(7) widely used in agricultural equipment; on machine tools as bases, brackets, and covers; for pipe fittings and cast iron pipe; and for automobile engine blocks, heads, manifolds, and water preps.
Cast is rarely used in structural work except for compression members. It is widely used in construction machinery for counterweights and in other applications for which weight is required.

b. Gray cast has low ductility and therefore will not expand or stretch to any considerable extent before breaking or cracking.
Because of this characteristic, preheating is necessary when cast is welded by the oxyacetylene welding process. It can, however, be welded with the metal-arc process without preheating if the welding heat is carefully controlled.
This can be accomplished by welding only short lengths of the joint at a time and allowing these sections to cool. By this procedure, the heat of welding is confined to a small area, and the danger of cracking the casting is eliminated.
Large castings with complicated sections, such as motor blocks, can be welded without dismantling or preheating. Special electrodes designed for this purpose are usually

desirable.

Ductile cast irons, such as malleable iron, ductile iron, and nodular iron, can be successfully welded. For best results, these types of cast irons should be welded in the annealed condition.

c. Welding is used to salvage new iron castings, to repair castings that have failed in service, and to join castings to each other or to steel parts in manufacturing operations. Table 7-19 shows the welding processes that can be used for welding cast, malleable, and nodular irons.

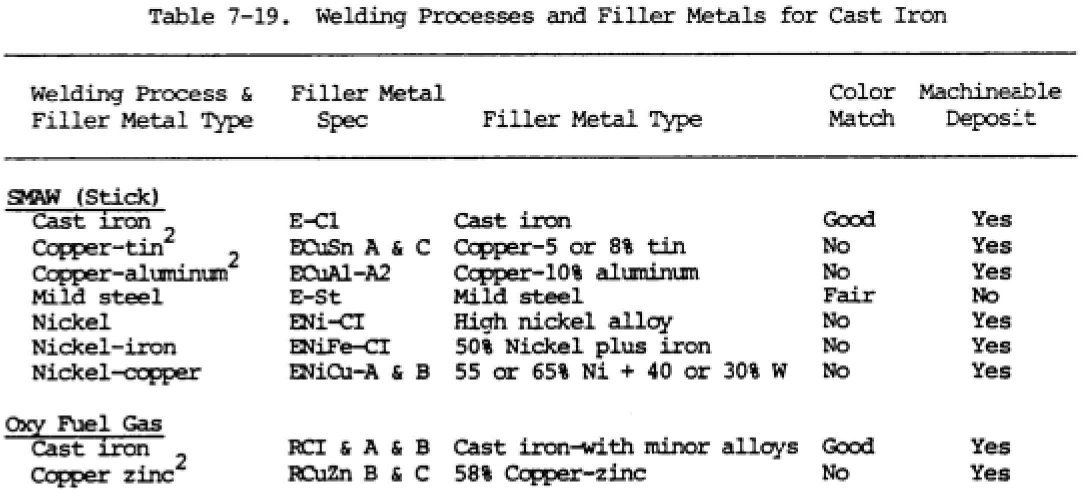


Table 7-19. Welding Processes and Filler Metals for Cast Iron

Welding Process & Filler Metal Type	Filler Metal Spec	Filler Metal Type	Color Match	Machineable Deposit
SMAW (Stick)				
Cast iron	E-C1	Cast iron	Good	Yes
Copper-tin[2]	ECuSn A & C	Copper-5 or 8% tin	No	Yes
Copper-aluminum[2]	ECuA1-A2	Copper-10% aluminum	No	Yes
Mild steel	E-St	Mild steel	Fair	No
Nickel	ENi-CI	High nickel alloy	No	Yes
Nickel-iron	ENiFe-CI	50% Nickel plus iron	No	Yes
Nickel-copper	ENiCu-A & B	55 or 65% Ni + 40 or 30% W	No	Yes
Oxy Fuel Gas				
Cast iron	RCI & A & B	Cast iron-with minor alloys	Good	Yes
Copper zinc[2]	RCuZn B & C	58% Copper-zinc	No	Yes

The selection of the welding process and the welding filler metals depends on the type of weld properties desired and the service life that is expected.

For example, when using the shielded metal arc welding process, different types of filler metal can be used. The filler metal will have an effect on the color match of the weld compared to the base material.

The color match can be a determining factor, specifically in the salvage or repair of castings, where a difference of color would not be acceptable.

d. No matter which of the welding processes is selected, certain preparatory steps should be made. It is important to determine the exact type of cast iron to be welded, whether it is gray cast iron or a malleable or ductile type. If exact information is not known, it is best to assume that it is gray cast iron with little or no ductility. In general, it is not recommended to weld repair gray iron castings that are subject to heating and cooling in normal service, especially when heating and cooling vary over a range of temperatures exceeding 400ºF (204ºC). Unless cast iron is used as the filler material, the weld metal and base metal may have different coefficients of expansion and contraction. This will contribute to internal stresses which cannot be withstood by gray cast iron. Repair of these types of castings can be made, but the reliability and service life on such repairs cannot be predicted with accuracy.

e. Preparation for Welding.

(1) In preparing the casting for welding, it is necessary to remove all surface materials to completely clean the casting in the area of the weld. This means removing paint, grease, oil, and other foreign material from the weld zone. It is desirable to heat the weld area for a short time to remove entrapped gas from the weld zone of the base metal. The skin or high silicon surface should also be removed adjacent to the weld area on both the face and root side. The edges of a joint should be chipped out or ground to form a 60º angle or bevel. Where grooves are involved, a V groove from a 60-90º included angle should be used. The V should extend approximately 1/8 in. (3.2 mm) from the bottom of the crack. A small hole should be drilled at each end of the crack to keep it from spreading. Complete penetration welds should always be used, since a crack or defect not completely removed may quickly reappear under service conditions.

(2) Preheating is desirable for welding cast irons with any of the welding processes. It can be reduced when using extremely ductile filler metal.
Preheating will reduce the thermal gradient between the weld and the remainder of the cast iron. Preheat temperatures should be related to the welding process, the filler metal type, the mass, and the complexity of the casting.
Preheating can be done by any of the normal methods. Torch heating is normally used for relatively small castings weighing 30.0 lb (13.6 kg) or less.
Larger parts may be furnace preheated, and in some cases, temporary furnaces are built around the part rather than taking the part to a furnace.
In this way, the parts can be maintained at a high interpass temperature in the temporary furnace during welding. Preheating should be general, since it helps to improve the ductility of the material and will spread shrinkage stresses over a large area to avoid critical stresses at any one point.
Preheating tends to help soften the area adjacent to the weld; it assists in degassing the casting, and this in turn reduces the possibility of porosity of the deposited weld metal; and it increases welding speed.

(3) Slow cooling or post heating improves the machinability of the heat-affected zone in the cast iron adjacent to the weld.
The post cooling should be as slow as possible. This can be done by covering the casting with insulating materials to keep the air or breezes from it.

Welding Technique.

(1) Electrodes.

(a) Cast iron can be welded with a coated steel electrode, but this method should be used as an emergency measure only. When using a steel electrode, the contraction of the steel weld metal, the carbon picked up from the cast iron by the weld metal, and the hardness of the weld metal caused by rapid cooling must be considered.
Steel shrinks more than cast iron when ceded from a molten to a solid state. When a steel electrode is used, this uneven shrinkage will cause strains at the joint after welding.
When a large quantity of filler metal is applied to the joint, the cast iron may crack just back of the line of fusion unless preventive steps are taken.
To overcome these difficulties, the prepared joint should be welded by depositing the weld metal in short string beads, 0.75 to 1.0 in. long (19.0 to 25.4 mm).
These are made intermittently and, in some cases, by the backstep and skip procedure.
To avoid hard spots, the arc should be struck in the V, and not on the surface of the base metal.
Each short length of weld metal applied to the joint should be lightly peened while hot with a small ball peen hammer, and allowed to cool before additional weld metal is applied.
The peening action forges the metal and relieves the cooling strains.

(b) The electrodes used should be 1/8 in. (3.2 mm) in diameter to prevent excessive welding heat. Welding should be done with reverse polarity.
Weaving of the electrode should be held to a minimum. Each weld metal deposit should be thoroughly cleaned before additional metal is added.

(c) Cast iron electrodes must be used where subsequent machining of the welded joint is required.
Stainless steel electrodes are used when machining of the weld is not required. The procedure for making welds with these electrodes is the same as that outlined for welding with mild steel electrodes.
Stainless steel electrodes provide excellent fusion between the filler and base metals.
Great care must be taken to avoid cracking in the weld, contracts approximately 50 percent more than because stainless steel expands and mild steel in equal changes of temperature.

(2) Arc Welding.

(a) The shielded metal arc welding process can be utilized for welding cast iron. There are four types of filler metals that may be used: cast iron covered electrodes; covered copper base alloy electrodes; covered nickel base alloy electrodes; and mild steel covered electrodes.

There are reasons for using each of the different specific types of electrodes, which include the machinability of the deposit, the color match of the deposit, the strength of the deposit, and the ductility of the final weld.

(b) When arc welding with the cast iron electrodes (ECI), preheat to between 250 and 800ºF (121 and 425ºC), depending on the size and complexity of the casting and the need to machine the deposit and adjacent areas.

The higher degree of heating, the easier it will be to machine the weld deposit. In general, it is best to use small-size electrodes and a relatively 1ow current setting.
A medium arc length should be used, and, if at all possible, welding should be done in the flat position. Wandering or skip welding procedure should be used, and peening will help reduce stresses and will minimize distortion.
Slow cooling after welding is recommended. These electrodes provide an excellent color match cm gray iron. The strength of the weld will equal the strength of the base metal.

There are two types of copper-base electrodes: the copper tin alloy and the copper aluminum types. The copper zinc alloys cannot be used for arc welding electrodes because of the low boiling temperature of zinc. Zinc will volatilize in the arc and will cause weld metal porosity.

(c) When the copper base electrodes are used, a preheat of 250 to 400ºF (121 to 204ºC) is recommended. Small electrodes and low current should be used.

The arc should be directed against the deposited metal or puddle to avoid penetration and mixing the base metal with the weld metal. Slow cooling is recommended after welding. The copper-base electrodes do not provide a good color match.

(d) There are three types of nickel electrodes used for welding cast iron.

These electrodes can be used without preheat; however, heating to 100ºF (38ºC) is recommended. These electrodes can be used in all positions; however, the flat position is recommended. The welding slag should be removed between passes.

The nickel and nickel iron deposits are extremely ductile and will not become brittle with the carbon pickup. The hardness of the heat-affected zone can be minimized by reducing penetration into the cast iron base metal.

The technique mentioned above, playing the arc on the puddle rather than on the base metal, will help minimize dilution. Slow cooling and, if necessary, postheating will improve machinability of the heat-affected zone. The nickel-base electrodes do not provide a close color match.

(e) Copper nickel type electrodes cane in two grades. Either of these electrodes can be used in the same manner as the nickel or nickel iron electrode with about the same technique and results. The deposits of these electrodes do not provide a color match.

(f) Mild steel electrodes are not recommended for welding cast iron if the deposit is to be machined. The mild steel deposit will pick up sufficient carbon to make a high-carbon deposit, which is impossible to machine.

Additionally, the mild steel deposit will have a reduced level of ductility as a result of increased carbon content. This type of electrode should be used only for small repairs and should not be used when machining is required.
Minimum preheat is possible for small repair jobs. Small electrodes at low current are recommended to minimize dilution and to avoid the concentration of shrinkage stresses.
Short welds using a wandering sequence should be used, and the weld should be peened as quickly as possible after welding.
The mild steel electrode deposit provides a fair color match.

(3) Carbon-arc welding of cast iron.
Iron castings may be welded with a carbon arc, a cast iron rod, and a cast iron welding flux.
The joint should be preheated by moving the carbon electrodes along the surface. This prevents too-rapid cooling after welding.
The molten puddle of metal can be worked with the carbon electrode so as to move any slag or oxides that are formed to the surface.
Welds made with the carbon arc cool more slowly and are not as hard as those made with the metal arc and a cast iron electrode. The welds are machinable.

(4) Oxyfuel gas welding.
The oxyfuel gas process is often used for welding cast iron. Most of the fuel gases can be used.
The flame should be neutral to slightly reducing.
Flux should be used.

Two types of filler metals are available: the cast iron rods and the copper zinc rods. Welds made with the proper cast iron electrode will be as strong as the base metal. Good color match is provided by all of these welding reds. The optimum welding procedure should be used with regard to joint preparation, preheat, and post heat. The copper zinc rods produce braze welds.
There are two classifications: a manganese bronze and a low-fuming bronze. The deposited bronze has relatively high ductility but will not provide a color match.

(5) Brazing and braze welding.

(a) Brazing is used for joining cast iron to cast iron and steels.
In these cases, the joint design must be selected for brazing so that capillary attraction causes the filler metal to flow between closely fitting parts.
The torch method is normally used.
In addition, the carbon arc, the twin carbon arc, the gas tungsten arc, and the plasma arc can all be used as sources of heat.
Two brazing filler metal alloys are normally used; both are copper zinc alloys.
Braze welding can also be used to join cast iron. In braze welding, the filler metal is not drawn into the joint by capillary attraction.
This is sometimes called bronze welding. The filler material having a liquidous above 850ºF (454ºC) should be used. Braze welding will not provide a color match.

(b) Braze welding can also be accomplished by the shielded metal arc and the gas metal arc welding processes.
High temperature preheating is not usually required for braze welding unless the part is extremely heavy or complex in geometry.
The bronze weld metal deposit has extremely high ductility, which compensates for the lack of ductility of the cast iron.
The heat of the arc is sufficient to bring the surface of the cast iron up to a temperature at which the copper base filler metal alloy will make a bond to the cast iron.
Since there is little or no intermixing of the materials, the zone adjacent to the weld in the base metal is not appreciably hardened.
The weld and adjacent area are machinable after the weld is completed. In general, a 200ºF (93ºC) preheat is sufficient for most application.
The cooling rate is not extremely critical and a stress relief heat treatment is not usually required.
This type of welding is commonly used for repair welding of automotive parts, agricultural implement parts, and even automotive engine blocks and heads.
It can only be used when the absence of color match is not objectionable.

(6) Gas metal arc welding. The gas metal arc welding process can be used for making welds between malleable iron and carbon steels. Several types of electrode wires can be used, including:

(a) Mild steel using 75% argon + 25% CO2 for shielding.

(b) Nickel copper using 100% argon for shielding.

(c) Silicon bronze using 50% argon + 50% helium for shielding.

In all cases, small diameter electrode wire should be used at low current.
With the mild steel electrode wire, the Argon-CO2 shielding gas mixture issued to minimize penetration. In the case of the nickel base filler metal and the Copper base filler metal, the deposited filler metal is extremely ductile.
The mild steel provides a fair color match. A higher preheat is usually required to reduce residual stresses and cracking tendencies.

(7) Flux-cored arc welding.
This process has recently been used for welding cast irons. The more successful application has been using a nickel base flux-cored wire.
This electrode wire is normally operated with CO2 shielding gas, but when lower mechanical properties are not objectionable, it can be operated without external shielding gas.
The minimum preheat temperatures can be used. The technique should minimize penetration into the cast iron base metal. Post heating is normally not required. A color match is not obtained.

(8) Studding.
Cracks in large castings are sometimes repaired by studding (fig. 7-10).

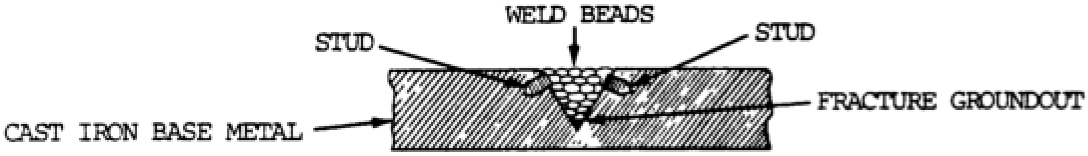


Figure 7-10. Studding method for cast iron repair.

In this process, the fracture is removed by grinding a V groove. Holes are drilled and tapped at an angle on each side of the groove, and studs are screwed into these holes for a distance equal to the diameter of the studs, with the upper ends projecting approximately 1/4 in. (6.4 mm) above the cast iron surface. The studs should be seal welded in place by one or two beads around each stud, and then tied together by weld metal beads. Welds should be made in short lengths, and each length peened while hot to prevent high stresses or cracking upon cooling. Each bead should be allowed to cool and be thoroughly cleaned before additional metal is deposited. If the studding method cannot be applied, the edges of the joint should be chipped out or machined with a round-nosed tool to form a U groove into which the weld metal should be deposited.

(9) Other welding processes can be used for cast iron.
Thermit welding has been used for repairing certain types of cast iron machine tool parts.
Soldering can be used for joining cast iron, and is sometimes used for repairing small defects in small castings.
Flash welding can also be used for welding cast iron

IRON AND STEEL

This page looks at the use of the Blast Furnace in the extraction of iron from iron ore, and the conversion of the raw iron from the furnace into various kinds of steel.

Extracting iron from iron ore using a Blast Furnace

Introduction

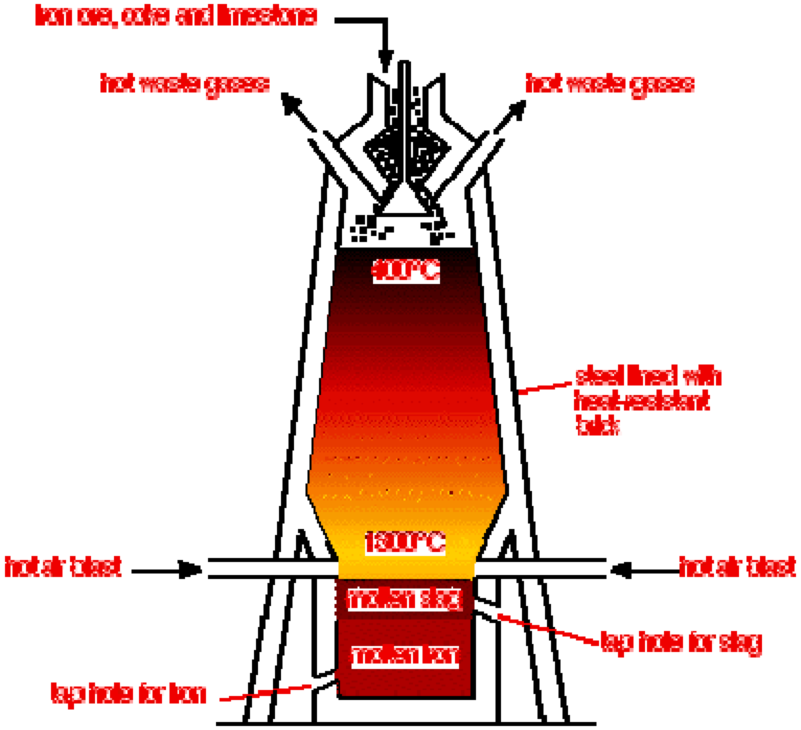
The common ores of iron are both iron oxides, and these can be reduced to iron by heating them with carbon in the form of coke. Coke is produced by heating coal in the absence of air.

Coke is cheap and provides both the reducing agent for the reaction and also the heat source - as you will see below.

Iron ores

The most commonly used iron ores are ***haematite*** (US: hematite), Fe_2O_3, and ***magnetite***, Fe_3O_4.

The Blast Furnace



The heat source

The air blown into the bottom of the furnace is heated using the hot waste gases from the top. Heat energy is valuable, and it is important not to waste any.

The coke (essentially impure carbon) burns in the blast of hot air to form carbon dioxide - a strongly exothermic reaction. This reaction is the main source of heat in the furnace.

$$C + O_2 \longrightarrow CO_2$$

The reduction of the ore

At the high temperature at the bottom of the furnace, carbon dioxide reacts with carbon to produce carbon monoxide.

$$C + CO_2 \longrightarrow 2CO$$

It is the carbon monoxide which is the main reducing agent in the furnace.

$$Fe_2O_3 + 3CO \longrightarrow 2Fe + 3CO_2$$

In the hotter parts of the furnace, the carbon itself also acts as a reducing agent. Notice that at these temperatures, the other product of the reaction is carbon monoxide, not carbon dioxide.

$$Fe_2O_3 + 3C \longrightarrow 2Fe + 3CO$$

The temperature of the furnace is hot enough to melt the iron which trickles down to the bottom where it can be tapped off.

The function of the limestone

Iron ore isn't pure iron oxide - it also contains an assortment of rocky material. This wouldn't melt at the temperature of the furnace, and would eventually clog it up. The limestone is added to convert this into ***slag*** which melts and runs to the bottom.

The heat of the furnace decomposes the limestone to give calcium oxide.

$$CaCO_3 \longrightarrow CaO + CO_2$$

This is an endothermic reaction, absorbing heat from the furnace. It is therefore important not to add too much limestone because it would otherwise cool the furnace.

Calcium oxide is a basic oxide and reacts with acidic oxides such as silicon dioxide present in the rock. Calcium oxide reacts with silicon dioxide to give calcium silicate.

$$CaO + SiO_2 \longrightarrow CaSiO_3$$

The calcium silicate melts and runs down through the furnace to form a layer on top of the molten iron. It can be tapped off from time to time as slag.

Slag is used in road making and as "slag cement" - a final ground slag which can be used in cement, often mixed with Portland cement.

Cast iron

The molten iron from the bottom of the furnace can be used as ***cast iron***.

Cast iron is very runny when it is molten and doesn't shrink much when it solidifies. It is therefore ideal for making castings - hence its name. However, it is very impure, containing about 4% of carbon. This carbon makes it very hard, but also very brittle. If you hit it hard, it tends to shatter rather than bend or dent.

Cast iron is used for things like manhole covers, guttering and drainpipes, cylinder blocks in car engines, Aga-type cookers, and very expensive and very heavy cookware.

Steel

Most of the molten iron from a Blast Furnace is used to make one of a number of types of steel. There isn't just one substance called steel - they are a family of alloys of iron with carbon or various metals. More about this later . . .

Steel-making: the basic oxygen process

Impurities in the iron from the Blast Furnace include carbon, sulphur, phosphorus and silicon. These have to be removed.

Removal of sulphur

Sulphur has to be removed first in a separate process. ***Magnesium powder*** is blown through the molten iron and the sulphur reacts with it to form magnesium sulphide. This forms a slag on top of the iron and can be removed.

$$Mg + S \longrightarrow MgS$$

Removal of carbon etc

The still impure molten iron is mixed with scrap iron (from recycling) and ***oxygen*** is blown on to the mixture. The oxygen reacts with the remaining impurities to form various oxides.

The carbon forms carbon monoxide. Since this is a gas it removes itself from the iron! This carbon monoxide can be cleaned and used as a fuel gas.

Elements like phosphorus and silicon react with the oxygen to form acidic oxides. These are removed using ***quicklime (calcium oxide)*** which is added to the furnace during the oxygen blow. They react to form compounds such as calcium silicate or calcium phosphate which form a slag on top of the iron.

Types of iron and steel

Cast iron has already been mentioned above. This section deals with the types of iron and steel which are produced as a result of the steel-making process.

Wrought iron

If all the carbon is removed from the iron to give high purity iron, it is known as wrought iron. Wrought iron is quite soft and easily worked and has little structural strength. It was once used to make decorative gates and railings, but these days mild steel is normally used instead.

Mild steel

Mild steel is iron containing up to about 0.25% of carbon. The presence of the carbon makes the steel stronger and harder than pure iron. The higher the percentage of carbon, the harder the steel becomes.

Mild steel is used for lots of things - nails, wire, car bodies, ship building, girders and bridges amongst others.

High carbon steel

High carbon steel contains up to about 1.5% of carbon. The presence of the extra carbon makes it very hard, but it also makes it more brittle. High carbon steel is used for cutting tools and masonry nails (nails designed to be driven into concrete blocks or brickwork without bending). You have to be careful with high carbon steel because it tends to fracture rather than bend if you mistreat it.

Special steels

These are iron alloyed with other metals. For example:

	iron mixed with	special properties	uses include
stainless steel	chromium and nickel	resists corrosion	cutlery, cooking utensils, kitchen sinks, industrial equipment for food and drink processing
titanium steel	titanium	withstands high temperatures	gas turbines, spacecraft
manganese steel	manganese	very hard	rock-breaking machinery, some railway track (e.g. points), military helmets

Some environmental considerations

This section is designed to give you a brief idea of the sort of environmental issues involved with the extraction of iron and its conversion to steel. I wouldn't claim that it covers everything!

Environmental problems in mining and transporting the raw materials

Think about:

- Loss of landscape due to mining, processing and transporting the iron ore, coke and limestone.
- Noise and air pollution (greenhouse effect, acid rain) involved in these operations

Extracting iron from the ore

Think about:

- Loss of landscape due to the size of the chemical plant needed.
- Noise.
- Atmospheric pollution from the various stages of extraction. For example: carbon dioxide (greenhouse effect); carbon monoxide (poisonous); sulphur dioxide from the sulphur content of the ores (poisonous, acid rain).
- Disposal of slag, some of which is just dumped.
- Transport of the finished iron.

Recycling

Think about:

- Saving of raw materials and energy by not having to first extract the iron from the ore.
- Avoiding the pollution problems in the extraction of iron from the ore.
- Not having to find space to dump the unwanted iron if it wasn't recycled.
- (Offsetting these to a minor extent) Energy and pollution costs in collecting and transporting the recycled iron to the steel works.

Cast Iron Welding Procedures

General

Cast Iron is considerably less weldable than low-carbon steel. Cast iron contains much more carbon and silicon than steel, with the result that cast iron is less ductile, and is more metallurgically deformed when welded. However, there have been many successful cast iron repair welds performed in maintenance and casting reclamation applications. The degree of brittleness and likelihood of cracking of the welded material will depend on the type of casting the heat treatment and the welding procedure.

Preparation

The most important aspect of welding cast iron is to have the surface clean and free of defects prior to welding, since castings that have been in service are likely to be impregnated with oil or grease. All surface contaminations should be removed with solvents, commercial cleaners, or paint removers. Casting skin should be removed from surfaces to be welded. Blind cracks and pits must be completely dressed out to sound metal by mechanical means such as grinding, chipping, rotary filling or shot blasting. Cracks should be excavated to their full length and depth. Excavate spongy areas and pinholes.

Impregnated oil or other volatile matter can be eliminated by using an oxidizing oxy-acetylene flame to heat the casting or weld groove to approximately 900 F for about 15 minutes and then wire brushing, grinding or rotary filling to remove the residue. This method has the advantage of de-gassing the casting and removing some of the surface graphite as well.

New castings present less of a cleaning problem than castings that have been in service. However, casting skin, sand, and other foreign materials must be removed from the joint to be welded and the adjacent surfaces of the casting.

To repair cracked castings, drill a hole at each end of the crack to prevent it spreading further and grind out to the bottom. Begin welding at the drilled end of the crack, where restraint is greatest and move towards the free end.

Casting which have to transmit fairly heavy working loads often have the weld joint assisted by mechanical means, such as bolt straps, or hoops which are shrunk on. Broken teeth of large cast iron gears are sometimes repaired by studding. Holes are dilled and tapped in the face of the fracture and mild steel studs screwed in. These are then covered with weld metal and build up to the required dimensions. They are machined afterwards or ground to shape.

Precautions when welding cast irons
Factors to consider are the same whatever the type of cast iron

1. Low ductility with a danger of cracking due to stresses set up by welding. (This is not so important when welding SG iron due to its good ductility)
2. Formation of a hard brittle zone in the weld area. This is caused by rapid cooling of molten metal to form a white cast iron structure in the weld area and makes the weld unsuitable for service where fairly high stresses are met.
3. Formation of a hard, brittle weld bead due to pick-up of carbon from the base metal. This does not occur with weld metals which do not form hard carbides such as Monel and high nickel alloys. These are used where machinable welds are desired.

Although much can be done without preheating, to avoid cracking (due to lack of ductility of castings, especially complicated shapes) may be minimized by suitable preheating.

In general all cast irons need to be pre-heated when oxyacetylene welding. This pre-heating reduces the welding heat-input requirements. High pre-heat is needed when using a cast iron filler metal because the weld metal has low ductility near room temperature. To avoid such pre-heating requirements, you may use Aufhauser NickelRod #99, with the base metal at or slightly above room temperature. The weld readily yields during cooling and relieves welding stresses that might otherwise cause cracking in the weld.

1. Local preheating occurs where parts not held in restraint may be preheated to about 500°C in the area of the weld, with slow cooling after welding is completed. Cracking from unequal expansion can take place during the preheating of complex castings or when the preheating is confined to a small area of a large casting> This is why local preheating should always be gradual.

2. Indirect preheating involves preheat of 200°C for other critical parts of the job in addition to local preheating. This is done so that they will contract with the weld and minimize contraction stresses. Such a technique is suitable for open frames, spokes etc.

3. Complete preheating is used for intricate casings, especially those varying in section thicknesses such as cylinder blocks. It involves complete preheating to 500°C followed by slow cooling after welding. The preheating temperature should be maintained during welding. A simple preheating furnace may be made of bricks into which gas jets project. Another may be filled with charcoal which burns slowly and preheats the job evenly.

Post weld Heating:
Post weld heat treatment may consist of either full annealing or stress relieving: when heat treatment is not applied, the welded casting is usually cooled slowly from the welding temperature to room temperature by covering it with insulating material such as lime, ground asbestos, or vermiculite.

Stress relieving at 1150°F and then furnace cooling to at least 700°F is recommended whenever feasible.

Full annealing at 1650°F is sometimes employed to produce greatest softening of the weld zone or a more complete stress relied. However, annealing lowers the as-cast tensile strength of all but the softest irons.

In critical applications that require radiographic or ultrasonic inspection after heat treatment, castings often are inspected before treatment also, to save unnecessary costs if an internal defect should be present.

Peening
Satisfactory welds may be made on cast iron without preheating by using electrodes depositing soft metals and peening the weld with a blunt tool (such as a ball hammer) immediately after welding. This spreads the weld metal and counteracts the effects of contraction. Good practice is to deposit short weld runs (50 mm at a time) and then peen before too much cooling takes place. (Aufhauser NickelRod #99 is soft and allows peening).

Shield metal-arc welding of cast irons
The most suitable electrodes for Shield metal-arc welding is Aufhauser NickelRod #99 and NickelRod #55.

Grey Cast Iron
NickelRod #99 is more suitable for single layers and for filling small defects as the deposit remains highly machinable. Single-layered welds of NickelRod #55 are not as machinable as NickelRod #99, however they do have increased strength and ductility. NickelRod #55 welds are more tolerant towards contaminants such as sulphur and phosphorous and are superior to NickelRod #99 electrodes when welding casting high in phosphorous.

Peening is a must for grey cast irons.

Joining of cast iron to steel can be performed with either cast NickelRod #55 or NickelRod #99, but NickelRod #55 is preferred. Ferrous based electrodes, including hydrogen controlled types are generally not recommended fro welding cast irons. Brackets, lungs and even wear plates can be attached to casting using the correct parameters and NickelRod #55.

Ductile cast iron
Ductile cast iron can only be repaired using NickelRod #55 due to its higher tensile strength and better ductility. When welding ductile cast irons, penetration should be low and wide joints or cavities should be built up fro the sides towards the centre. Stringer beads or narrow weaves should be used. Deposits short beads and allow cooling to preheat temperature. Peening is advisable but not as critical as when welding grey cast iron.

Austenitic cast irons

These are usually welded with NickelRod #55. Although austenitic castings can be welded with NickelRod #55 the weld may be unsuitable for applications where corrosion/hear resistance qualities do not match the parent metal.

GMAW

Cast irons are generally considered unweldable using the GMAW process.

FCAW welding of cast irons

Flux cored welding of cast iron is carried out using higher current than that for Shielded metal-arc welding. This is offset by faster travel speeds as for normal Flux Cored Arc Welding. Both grey, ductile and malleable cast irons can be welded using the Flux Cored Arc Welding process. Preparation and heat treatment are much the same as for shield. NickelRod #55 and NickelRod #99 are most suitable for FCAW welding of cast irons.

Oxy-acetylene welding of cast irons

For successful oxy fusion welding, it is essential that the part be pre-heated to a dull, red heat (approximately 650°C). A neutral or slightly reducing flame should be used with welding tips of medium or high flame velocity. The temperatures should be maintained during welding. As with Shielded Metal Arc Welding preparation it is necessary to use a furnace to ensure even heating of large castings. It is important that the casting be protected from draught during welding and provision should be made to ensure that the required preheat is maintained. It is important to avoid sudden chilling of the casting otherwise white cast iron may be produced which is very hard and brittle. This may cause cracking or make subsequent matching impossible.

Oxy welding is suitable for grey cast irons with an AWS A5.15 RCI (Aufhauser RCI), RCI-A type electrode and should used with a suitable flux such as Aufhauser Cast Iron Flux.

Austenitic cast irons can only be oxy welded with an AWS RCI-B type consumable.

Braze welding of cast irons

Braze welding should only be used to repair old casting because of the poor color match achieved with newer castings. Braze welding is suitable for grey, Austenitic and malleable cast irons, however joint strength equivalent to fusion welds are only possible with grey cast iron. A neutral or slightly oxidizing flame should be used.

Technical and trade information

Braze welding has advantages over oxy welding in that the consumable melts at a lower temperature than the cast iron. This allows lower preheat (320-400°C). As with other forms of welding the surface must be properly cleaned so that carbon doesn't contaminate the weld deposit.
The application consumables to use are AWS RBCuZn-C (Aufhauser 681 Low-Fuming Bronze) Types and AWS RBCuZn-D (Aufhauser 773 Nickel Silver) Types.

Brazing of cast irons

Any brazing processes suitable for steel are applicable to cast irons. Pre- and Post-braze operations should be similar to that of a standard brazing processes. Consumables suitable for brazing carbon steel can be used for cast irons.

Powder Spraying of cast irons

Powder spraying is particularly suited to edges, corners, shallow cavities and thin sections as there are usually no undercut marks. Porous areas must be ground out o a saucer or cup shape with no overhanging edges. Sharp corners, edges and protruding points must be removed or radiuses as they may go into solution in the molten metal causing hard spots.

Spraying and fusing should be as per the normal powder spraying process.

Poor quality or difficult irons can be joined by coating both parts separately with 1-2 mm of spray-fused alloy and then joining the coating together with a suitable nickel Shielded Metal Arc Welding electrode. Consumables are based on a nickel-silicon-boron mixture.

Soldering of cast iron is usually limited to the repair of small surface defects, often sealing areas from leakage of liquid or gases. The casting must be thoroughly cleaned.

Brazing / Soldering Flux

Brazing Flux plays a vital role in virtually all air brazing processes. Use of the wrong flux or a poor application technique can have a dramatic effect on joint quality.

Soldering Fluxes are classified as corrosive, intermediate or non-corrosive. The choice depends on the metals being joined, the melting range of the solder and whether the residues are to be removed after soldering.

There are also special fluxes for brazing tungsten carbide, stainless steel brazing, induction brazing, brazing aluminum bronze, manufacturing flux coated rods, reducing red staining on brass and brazing refractory metals.

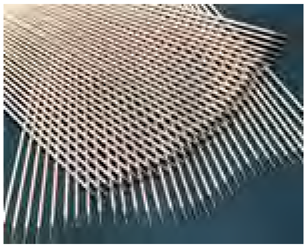
Flux Selection Chart

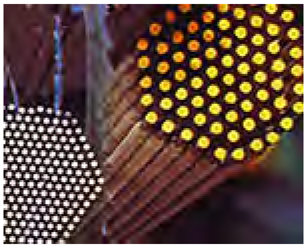
Flux Name	Base Metal	Recommended Filler Metal	Form	Applications / Description	ActiveTemp.	Specification
Flux For General Welding / Brazing						
Flux10	Aluminum And Aluminum-Based Alloys	Most Aluminum Brazing Alloys	Paste, Powder	Automotive, Air-Conditioning	1080-1140° F	N/A
Flux600	Bronze, Copper Brass, And Steel	Low Fuming Bronze And Nickel Silver	Paste, Powder	Farm Machinery	1400-2200° F	AMS 3417AWS Type FB3J
Flux17	Stainless Steels, High Chrome Alloy And Carbides	Nickel Silver, Brass And Bronze, Low Silver Alloys	Powder	Carbide Tools, Restaurant Appliance Mining Tools	1400-2200° F	AWS Type 3D
Flux11	Cast And Malleable Iron	Low Fuming Bronze	Powder	Maintenance, Marine Engines	1500-2000° F	Mil-F-16136B
Flux800	Cast Iron	Cast Iron	Powder	All Cast To Cast Iron Joining	950-1300° F	N/A
Flux-900	Magnesium And Magnesium Alloys	Equivalent Magnesium Filler Metals	Paste, Powder	Fabrication Of Magnesium Alloys	950-1300° F	Mil-F-6943a
Stainless Steel Flux	Gas Welding Of Stainless Steel And	Equivalent Stainless Steel Or High	Powder	Industrial Equipment And Maintenance	1500-2900° F	Mil-F-7516b Classes 1 & 2

	High Chromium Ferrous Alloys	Chrome Alloys				
Back-Side Stainflux	Series 300 And 400 Stainless Steel	Equivalent Stainless Steel Or High Chrome Alloys	Powder	TIG & MIG Welding Of Stainless Steel	2000-2900° F	Mil-F-7516b Classes 2 & 4
Flux14	Aluminum Sheets And Aluminum Based Alloy Sheets	Most Aluminum Based Alloy Sheets, And Stripes	Powder	Aluminum Sheets Air-Craft, Air Conditioning, Home Building	1080-1350° F	AMS 3414 Mil-F-6939b
Flux52	Zinc Die Cast	Zinc Die Casting, POT Metal And Dow Metal	Salt Powder	Zinc Die Casting, DOW Metals	600-1000° F	N/A
Flux for Silver Brazing / Soldering						
White SilverFlux	Ferrous And Non Ferrous, Stainless Steels, Carbides And High Chrome Alloys	All Silver AlloysAWS Classes BAg and BCuP	Paste, Powder	Air-Conditioning, Appliance, Plumbing, Carbide Tools	1100-1600° F	AMS 3410FAWS Type 3A
Black SilverFlux	Ferrous And Non Ferrous Alloys With Large Amount Of Refractory Oxides	All Silver AlloysAWS Classes BAg and BCuP	Paste, Powder	Carbide Tools, Mining Tools	1100-1700° F	AMS 3411AWS Type 3CO-F-499D Type B
Flux505	Ferrous and Non Ferrous Suitable For Soft Soldering	Soft Solders, All Commercial Grades Tin/Lead, Tin/Silver, Tin/Antimony	Paste, Powder	Plumbing, Air-Conditioning	300-500° F	O-F 506c Type 1, Form B
SolderFlux (Liquid)	Ferrous Alloys And Stainless	Tin/Lead, Tin/Silver, Tin/Antimony	Liquid	Recommend For Soldering Of Most	200-600° F	Fed O-F-506c Type 1, Form B

	Steel	Solder		Metals Except: Aluminum, Magnesium And Titanium		
Liquid Flux For Production Welding / Brazing						
SpeedFlux Type LPG	Steel, Copper, Bronze, Most Ferrous And Non-Ferrous	Steel, Bronze Rods, Nickel-Silver Rods, And Silver Solder	Liquid	Use With All Liquefied Petroleum Gas Systems For Production	1400-2000° F	N/A
SpeedFlux Type B-2	Steel, Copper, Bronze, Most Ferrous And Non-Ferrous	Steel, Bronze Rods, Nickel-Silver Rods, And Silver Solder	Liquid	Use With Oxyacetylene Torch For High Speed Production Of All Surface Brazing, Tubular Steel Furniture And Much More.	1400-2000° F	N/A

Maintenance Welding Rods And Electrodes





AL-43 Coated Aluminum Electrode Welding Rods (E4043)	This general purpose electrode possesses superior fluidity. It provides dense, quiet arc with spatter free deposits and easy slag removal. Is a good color match to commercial aluminum. With its extruded coating, AL-43 is the smoothest aluminum electrode commercially available. Tensile strength up to 28,000 psi.
Groovees slicing piercing gouging	No oxygen or air supply required Use with A.C. or D.C. plant without additional attachments. Great for cast iron, non-ferrous metals, cast and stainless steels. It leaves a clean scale-free surface with no further preparation. Free from carbon pick-up.
Aluminum Flux-Core Electrode for cast and wrought aluminum	An all position, general purpose electrode, Aluminum Flux-Core is corrosion resistant and provides perfect matching of color (darker upon anodizing). It is a state of the art all-purpose aluminum torch alloy for cast sheet or wrought aluminum with flux in the core.
773 Nickel Silver (RBCuZn-D)	Used for brazing Tungsten carbides, copper alloys, nickel alloys, stainless steels & carbon steels. Good color match to stainless steel, and is a low cost alternative to silver brazing alloys.

SuperBlue	A versatile, multi-purpose electrode welding rods, suitable for welding wrought and cast alloys such as high carbon, tool steels, stainless steels, spring steels, manganese steels and dissimilar steels. This alloy has excellent impact and frictional resistance with high heat resistance and mild abrasive resistance.
NickelRod #99 (ENiCl) for cast iron	With this extruded electrode welding rod, the weld deposit is predominantly nickel, hence the welds are hard, yet machinable. Excellent for joining, filling and buildup of all special cast irons. Exceed specs. for AWS ENiCI.
NickelRod #55 for cast iron	The weld deposit contains less nickel than #99 and is more easily machinable. The arc is stable, bead shape is excellent and the deposits are smooth and uniform. The narrow weld fusion zone reduces the hard areas of the HAZ to a minimum. Exceeds specs for AWS ENiFeCI.
Aufhauser RCI For Cast Iron	Suitable for full fusion welding of cast iron, providing a high strength weld metal which is easily machinable. It gives an excellent color match and has the same structure as gray cast iron. Use Cast Iron Flux.

Frequently Asked Questions

Q. How do I TIG weld alloy C91000?

A: For TIG welding, you can use our Phos Bronze A or our Silicon Bronze rod. Phos Bronze A gives better color match. Silicon Bronze gives stronger welds. The TIG welding temp. for both of these filler metals is a little higher than the melting point of the C91000 (1505 Solidus 1760 Liquidus). Because of this temperature question, and depending on the thickness of the welded part, you may want to consider brazing. To braze C91000, you may use our Phos Copper 0 alloy.

Q. How many rods per lb. ?

A: The number of rods per pound (or per kg.) varies with the alloy and with the diameter.
Here are a few commonly used alloys and diameters.

Diameter\Product	ALUM 4043	BARE #681	FC #681
	Weight (LB)		
1/16	96	32	23
3/32	44	14	13
1/8	27	8	7

Q. Brazing Concepts: Solidus, Liquidus and Brazing Range

A: When brazing, the terms melting point and freezing point are not properly used, unless you are dealing with an unalloyed metal.
Almost all brazing filler metals are alloys (combinations of elements). You cannot simply guess the melting point of an alloy by figuring the weighted average of the melting points of its elements. Usually, alloys are mixtures that melt little by little through a range of temperatures. A metallurgist makes a distinction between a pure metal’s melting point and a brazing filler metal’s melting range.

Solidus
The temperature at which an alloy begins to melt.

Liquidus
The temperature above which an alloy is completely molten.

Eutectic Point
An alloy is an “Eutectic composition” if it has a specific melting point like that of a pure metal. A Eutectic alloys melting range is small: solidus and liquidus are almost equal. The melting point in this case is called the “eutectic point”.

Brazing Range

To ensure a free flowing action, brazing usually requires temperatures above the liquidus. But, for example when brazing joints with a wide gap, you may need a more pasty, sluggish brazing filler metal that will not flow all over the joint. Sometimes, then, the low end of the brazing range for certain brazing filler metals is below the liquidus.

Q: I am experiencing a weld cracking problem on our TIG (GTAW) production line where we weld thinner sections of 6xxx series aluminum metal sheets using aufhauser 4043 filler material. Why do you think my welds are cracking? And why is it that not all of my welds, but only some of them are cracking?

A: The aluminum/magnesium/silicon base alloys (6xxx series) are highly crack sensitive because they contain approximately 1 % Magnesium Silicide (Mg_2Si), which falls close to the peak of the solidification crack sensitivity curve.

The Mg_2Si content of these materials is the primary reason that there are no 6xxx series filler alloys made. The cracking tendency of these alloys is lowered to acceptable levels during arc welding by the dilution of the weld pool with excess magnesium (by use of the 5xxx series Al-Mg filler alloys) or excess silicon (by use of the 4xxx series Al-Si filler alloys).

When we TIG (GTAW) weld on thin material, it is often possible to produce a weld, particularly on corner joints, by melting both edges of the base material together without adding filler material. In the majority of arc welding applications with this base material, we must add filler material if we want to have consistently crack free welds. A possible exception would be counteracting the cracking mechanism by maintaining a compressive force on the parts during the welding operation, which requires specialized fabrication techniques and considerations. This method is seldom used.

I suspect that the welds in question that are not cracking are those that have had filler material added during welding. My advice would be to ensure that filler alloy is added to all welds during welding in order to reduce crack sensitivity. Consideration should also be given when evaluating the cause of cracking to any differences in welds associated with weld size, and variations in tensile stresses introduced by shrinkage, joint expansion, or externally applied loads.

Q: What is the tensile strength of brazed joints

A: It all depends
No manufacturer lists the tensile strength of their brazing alloys.
This is not to make life difficult for the ultimate consumer. It's because people tend to place to much emphasis on any number that might be published. Design engineers sometimes base designs on a number that's not appropriate for the ultimate use.

In fact, the strength of a brazed joint depends more on the design and the brazing procedure then on the filler metal used.

Furthermore, tensile strength numbers thaw Aufhauser has measured apply to material in the wrought state. When the filler metal is used in brazing, it is effectively recast. Recast metal has different properties from the wrought metal.

Empirical testing of various brazed joints has shown that the PSI of the alloy does not correlate directly to the strength of the tested joint. We know some of the factors that influence this process. For example, if the alloy is overheated, the lower melting elements are burned off to a higher degree. This effectively changes the composition of the deposited metal. Thus our advice is to encourage customers to do their own testing of the brazed joint.

But there are some rules of thumb
If customers insist on a certain PSI number, we suggest a number ranging from 60,000-70,000 PSI when tested in the wrought state.

Another rough guideline is that joints properly brazed with Aufhauser Silver alloys have a shear strength that exceeds three times the shear strength of the thinner, joined metal.

Q: Joining aluminum to copper

A: It is difficult to braze or weld aluminum to copper, because of the low melting temperature (1018 F) of the aluminum-copper eutectic and its extreme brittleness. By heating and cooling rapidly, however, reasonably ductile joints are made for applications such as copper inserts in aluminum castings. The usual filler metals and fluxes for brazing aluminum to aluminum can be used, or the silver alloy filler metals BAg-1 and BAg-la can be used if heating and cooling are rapid (to minimize diffusion). Pretinning the copper surfaces with solder or silver alloy filler metal improves wetting and permits shorter time at brazing temperature. A more practical way to braze aluminum to copper is to braze one end of a short length of aluminum-coated steel tube to the aluminum, and then silver braze the other

http://www.brazing.com/techguide/FAQ.asp - FAQ

Wire Gauge / Gage Conversion Chart

S.W.G.	Wire Number	A.W.G. or B&S	A.W.G. Metric
(Inches)	(Gauge)	(Inches)	(MM)
0.500	0000000 (7/0)	....	....
0.464	000000 (6/0)	0.580000	....
0.432	00000 (5/0)	0.516500	....
0.400	0000 (4/0)	0.460000	11,684
0.372	000 (3/0)	0.409642	10,404
0.348	00 (2/0)	0.364796	9,266

0.324	0 (1/0)	0.324861	8,252
0.300	1	0.289297	7,348
0.276	2	0.257627	6,543
0.252	3	0.229423	5,827
0.232	4	0.2043	5,189
0.2120	5	0.1819	4,621
0.1920	6	0.1620	4,115
0.1760	7	0.1443	3,665
0.1600	8	0.1285	3,264
0.1440	9	0.1144	2,906
0.1280	10	0.1019	2,588
0.1160	11	0.0907	2,304
0.1040	12	0.0808	2,052
S.W.G.	**Wire Number**	**A.W.G. or B&S**	**A.W.G. Metric**
0.0920	13	0.0720	1,829
0.0800	14	0.0641	1,628
0.0720	15	0.0571	1,450
0.0640	16	0.0508	1,291
0.0560	17	0.0453	1,150
0.0480	18	0.0403	1,024
0.0400	19	0.0359	0,9119
0.0360	20	0.0320	0,8128
0.0320	21	0.0285	0,7239
0.0280	22	0.0253	0,6426

0.0240	23	0.0226	0,5740
0.0220	24	0.0201	0,5106
0.0200	25	0.0179	0,4547
0.0180	26	0.0159	0,4038
0.0164	27	0.0142	0,3606
0.0148	28	0.0126	0,3200
0.0136	29	0.0113	0,2870
0.0124	30	0.0100	0,2540
0.0116	31	0.0089	0,2261
0.0108	32	0.0080	0,2032
0.0100	33	0.0071	0,1803
S.W.G.	**Wire Number**	**A.W.G. or B&S**	**A.W.G. Metric**
0.0092	34	0.0063	0,1601
0.0084	35	0.0056	0,1422
0.0076	36	0.0050	0,1270
0.0068	37	0.0045	0,1143
0.0060	38	0.0040	0,1016
0.0052	39	0.0035	0,0889
0.0048	40	0.0031	0,0787
0.0044	41	0.0028	0,0711
0.0040	42	0.0025	0,0635
0.0036	43	0.0022	0,0559
0.0032	44	0.0020	0,0508
0.0028	45	0.0018	0,0457

0.0024	46	0.0016	0,0406
0.0020	47	0.0014	0,0350
0.0016	48	0.0012	0.0305
0.0012	49	0.0011	0,0279
0.0010	50	0.0010	0,0254
	51	0.00088	0,0224
	52	0.00078	0,0198
	53	0.00070	0,0178
	54	0.00062	0,0158
	55	0.00055	0,0140
	56	0.00049	0,0124

Wire Gauges / Gages Arranged In Columns As Follows:

AWG= American Wire Gauge

B&S= Brown & Sharpe

SWG= Imperial Standard Wire Gauge-(British legal standard)

Wire Gauge /Gage Comment:

Values are stated in approximate decimals of an inch excluding the metric numbers. As a number of gauges are in use for various shapes and metals, it is advisable to state the thickness in thousands when specifying in gauge number. Metric wire gauge is 10 times the diameter in millimeters.

Key Metals: Melting Point Information

Metal or Alloy	Melting Point	
	°F	°C
Aluminum, pure	1218	658
Brass and Bronze	1600-1660	871-904
Copper	1981	1083
Iron, Cast and Malleable	2300	1260
Lead, Pure	620	327
Magnesium	1240	671
Monel	2400	1316
Nickel	2646	1452
Silver, Pure	1762	961
Steel, Hi-Carbon (0.40% to 0.70% carbon)	2500	1371
Steel, Medium Carbon (less than 0.15%)	2700	1482
Steel, Low Carbon (0.15% to 0.40% carbon)	2600	1427
Stainless Steel (18% Chromium, 8% Nickel)	2550	1399
Titanium	3270	1799
Tungsten	6152	3400
Zinc, Cast or Rolled	786	419

Diameter of Wire		Welding or Brazing Alloy									**Flux-Cored Steel Electrode**
Decimal Inches	**Fraction Inches**	**Aluminum**	**Bronze, Alum. 10%**	**Bronze, Silicon**	**Copper (deox.)**	**Copper Nickel**	**Magnesium**	**Nickel**	**Steel, Mild**	**Steel, Stainless**	
0.02	---	32400	11600	10300	9800	9950	50500	9900	11100	10950	---
0.025	---	22300	7960	7100	6750	6820	34700	6820	7680	7550	---
0.03	---	14420	5150	4600	4360	4430	22400	4400	4960	4880	---
0.035	---	10600	3780	3380	3200	3260	16500	3240	3650	3590	---
0.04	---	8120	2900	2580	2450	2490	12600	2480	2790	2750	---
0.045	3/64	6410	2290	2040	1940	1970	9990	1960	2210	2170	2375
0.062	1/16	3382	1120	1070	1020	1040	5270	1030	1160	1140	1230
0.078	5/64	2120	756	675	640	650	3300	647	730	718	996
0.093	3/32	1510	538	510	455	462	2350	460	519	510	640
0.125	1/8	825	295	263	249	253	1280	252	284	279	346
0.156	5/32	530	189	169	160	163	825	162	182	179	225
0.187	3/16	377	134	120	114	116	587	115	130	127	---
0.25	1/4	206	74	66	32	64	320	63	71	70	---

Table gives approximate inches per lb of wire. In the case of flux coated wire, inches per lb will be about 10-20% higher.