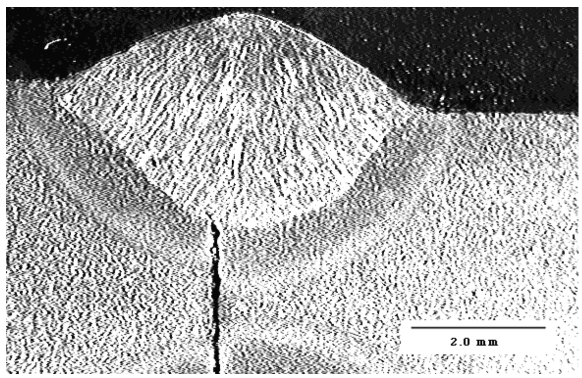
WELDING AND ALLIED PROCESSES*

NPRE 432

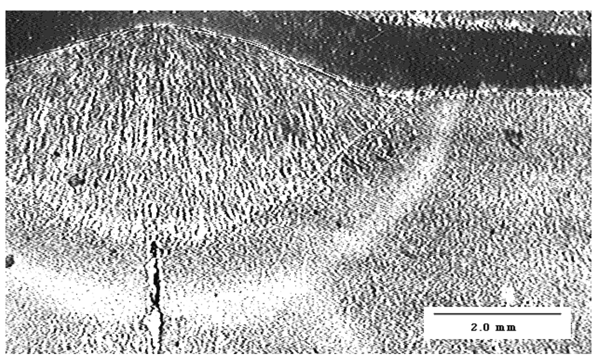
Engineering Materials

Lab 7

Fall 2020



1045 Steel. Low Power Weld



1045 Steel. Normal Power Weld

* Taken from ME 330 Lab 8 Spring 2020

I. INTRODUCTION

Nearly all products, machines, and structures are an assembly of parts. Consequently, fastening and joining processes are essential parts of design and manufacturing. Rivets and bolts are examples of fasteners. Welding, brazing, soldering, and application of adhesives are used for joining. Of all the joining processes, welding is the most adaptable and generally provides the strongest connection. Since the use of welding in industry is ubiquitous, a working knowledge of these processes is vital for designers and fabricators.

The objectives of this laboratory experiment are:

1.Become familiar with the different types of welding processes.

2.Apply the knowledge from previous labs to analyze structures and mechanical properties.

3.Compare the mechanical properties of welded specimens and joints.

II. WELDABILITY

Weldability classifies the ease of welding a metal. This term can be defined as the ability of a metal to be welded into a structure with certain properties to meet specific service requirements. To understand weldability, it is necessary to understand the parameters that affect the results of a welding process.

A. Allied Processes

Welding is distinguished from the other joining processes by the fact that the base metal of the workpieces being joined is melted. Although a filler metal is often used, autogenous welds are not uncommon. An autogenous weld is a joint consisting of the molten and resolidified base metal without a filler metal. Conversely, brazing and soldering are accomplished without melting the workpiece. The joint is made by melting a filler metal to provide the connection between workpieces. In a sense, soldering and brazing are more like adhesive joining than welding.

B. Major Variables

The various welding processes may be grouped into three categories: the method used to supply heat to the weld; the cleaning and preparation of the joint faces; and the prevention of contamination from the air during welding. Typical classifications for generating heat are:

(1) **Mechanical:** Heat is generated by friction between the workpieces or from rapid local deformation of the material. An example of the former is friction welding, which is used to join shafts, tubes, and to connect rods and studs onto larger bodies. One of the workpieces is rotated at high rate and then the workpieces are forced together. The friction between the two surfaces generates enough heat to liquefy the metal and fuse the components.

(2) **Thermochemical:** Heat is supplied by an exothermic chemical reaction. Two examples are flame welding and plasma arc welding.

(3) **Electrical Resistance:** Heat is generated by the resistance of the workpiece to a large electric current. An example is spot-welding.

(4) **Electric Arc:** Heat is supplied by an arc between an electrode and the workpiece. This process is typically performed at low voltages and high currents. A common example is gas-tungsten arc welding.

(5) **Radiation:** Heat is supplied by a suitably focused beam of radiation. Examples include electron beam welding and laser welding.

Shielding the weld is important because nitrogen and oxygen, which together comprise most of the atmosphere, readily form undesirable products in the molten weld pool. Other elements may cause detrimental results such as hydrogen cracking. A cloud of inert gas is commonly used to prevent these elements from entering the weld pool. This shielding is accomplished in many welding processes by flowing inert gases such as argon, helium, or carbon dioxide. Another approach is to use a byproduct of the welding process itself to protect the weld. For example, the combustion products from the flame in gas welding form a gas that shields the weld. Another method is the use of a flux, which melts and flows over the molten metal, providing a barrier against atmospheric contaminants. As in soldering and brazing, flux is a corrosive medium that chemically removes surface contaminants to clean the metal.

III. WELDING PROCESSES

There are several common welding processes of interest to the engineer. These include arc welding, gas welding, resistance welding and laser welding.

A. Arc Welding Processes

During arc welding, an electric arc is created between the electrode and the workpiece that melts a localized region of the workpiece, thus forming the weld. The different arc welding processes vary as to how the weld region is shielded and the use of a filler metal.

Shielded-Metal Arc Welding (SMAW), commonly known as “stick welding”, uses a consumable flux-coated electrode. The electrode is usually a 30 cm long rod, gripped in an electrode clamp. SMAW is one of the most common welding processes due to its low cost and portability. Arc voltages are typically around 20V, with currents between 50 and 500 Amps. The arc melts both the base metal and the electrode to form the weld. The covering of the electrode contains flux, which cleans the surface ahead of the weld and protects the molten weld surface by supplying a gaseous shield. The flux forms a glassy coating over the weld that must be removed after the weld is completed.

Arc welds can be made using AC or DC electric current. AC is convenient because the electric utility supply can be used without modification. However, DC provides more consistent and controllable results. DC straight polarity (DCSP - workpiece is positive and the electrode is negative) is the most common SMAW practice, because it gives good penetration and a narrow weld. Most of the heat is generated on the positive side of the circuit, so DCSP produces most of the heat in the workpiece. Conversely, DC reversed (DCRP - workpiece is negative) produces more heat in the electrode resulting in less penetration and a wider, shallower weld.

Electrodes are selected on the basis of chemical alloy composition, desired mechanical properties and operating (arc) characteristics. The resulting weld metal is a mixture of the base and filler metal, so predicting the properties of the weld is difficult. Electrodes are coded using a four-digit number, such as E6010 where:

E indicates the rod is for electric arc welding,

60 indicates a minimum UTS of 60 ksi in the weld deposit,

10 indicates the coating, polarity, and the allowable positions (i.e. vertical, overhead, etc.).

Three common electrodes are E6010, E6013, and E7018.

Two other common arc-welding processes are Gas Metal Arc Welding (GMAW) and Gas Tungsten Arc Welding (GTAW), also known as MIG (Metal Inert Gas) and TIG (Tungsten Inert

Gas) respectively. During these processes an inert gas is flowed onto the workpiece through a shroud around the electrode. GMAW uses a consumable electrode, usually a wire fed continuously through the electrode holder allowing long, continuous welds. The tungsten electrode is not consumed during GTAW welding. Filler metal must be added separately.

B. Gas Welding

The most common gas welding process is oxyacetylene welding (OAW). Methylacetylene propadiene (MAPP) is also used in certain situations because of safety concerns since acetylene can be dangerous and unstable. Propane is used for many brazing and soldering applications, but the flame generally is not hot enough for welding. For welding, the fuel gas is generally mixed with pure oxygen rather than air to maximize the flame temperature.

Three properties of the gas are important: flame temperature, flame propagation rate and the heat liberated during combustion. Since the metal must be melted, the flame temperature limits the possible fuels for welding. For the candidate fuels, the heat of combustion usually governs the final choice. Acetylene has a considerably greater heat of combustion than MAPP and other fuels, so it continues to be used despite safety issues.

The advantages of gas welding include its versatility, portability, and cost. Gas welding equipment is easily transported, and the flame can be used for other jobs such as brazing, preheating, and cutting. The equipment and supplies are relatively inexpensive, and the gas flame is easier to control than an electric arc. Additionally, the gas weld has less penetration, which makes it ideal for light welding of products such as sheet metal.

The flame is not as hot as an electric arc, so gas welding is slower than most other welding processes. The prolonged heating tends to heat more of the workpiece and the cooling time is longer. The result may be less desirable microstructures in the weld. Additionally, the slow rate of heat input results in an overall larger heat input to complete a weld, so a larger heat-affected zone results. Distortion and residual stresses due to uneven thermal expansion and contraction are also more of a concern. Finally, the shield provided by carbon dioxide and carbon monoxide (combustion products from the gas flame) is not as effective in protecting the weld as the gases used with other welding methods.

C. Resistance Welding

Resistance welds use electricity to heat the metal with the heat resulting from the resistance of the metal to a high current (I^2R) rather than by an arc. The most common resistance welds are spot welds, which also use pressure between the two workpieces to assist forming the weld. The weld forms a nugget, a small melted zone joining the two pieces. Spot welding is used extensively in manufacturing to join sheet metal components, for instance in the automobile industry.

D. Laser Beam Welding

Laser beam welding (LBW) is a relatively new process that uses a beam of radiation to supply heat. LBW is increasing in popularity due to its potential for automation. A laser is a coherent beam of photons of the same wavelength and at fairly high energy levels. This beam is focused to supply enough energy to melt the metal at the desired location. Laser beam welding is fast and fairly clean. Shielding is supplied by a separate flow of inert gas. Deep, narrow weld penetration can be achieved due to the high-energy intensity of the beam. Thus, the heat-affected zone formed from laser welding is considerably smaller than in conventional welding processes. A wide range of dissimilar metals that cannot be welded by any other process can be joined with laser welding. Although the cost of the laser is relatively high compared to the other processes discussed above, laser welding provides enough advantages to make it cost-competitive with the other options.

IV. Welding Metallurgy

When a metal is welded, the rapid and extensive temperature changes cause substantial changes in the local microstructure resulting in important property changes. As a result, there are three important zones formed in the material during welding: the fusion zone, the heat-affected zone, and the base metal.

A. Fusion Zone

As shown in Figure 1, the regions where the maximum temperature exceeds the solidus temperature melt and form the fusion zone (FZ) that has properties of "as cast" metal. This zone will often be softer than the base metal, especially if it is a cold worked material. However, alloys may be added to this zone during welding and affect the final composition and properties.

B. Heat-Affected Zone

Next to the fusion zone, the metal has been heated to various temperatures below the melting point. Further away from the weld, the base metal remains unaffected. Between the fusion zone and base metal is the heat-affected zone (HAZ). This region has been heated sufficiently to cause microstructural changes and it generally contains the weakest part of the weld. In a cold worked metal, the high temperatures experienced in the HAZ will cause recrystallization and grain growth, effectively annealing and softening the metal as shown in Figure 1. In the HAZ of a precipitation-hardened metal, the strengthening precipitates can coarsen or dissolve, weakening the material. In

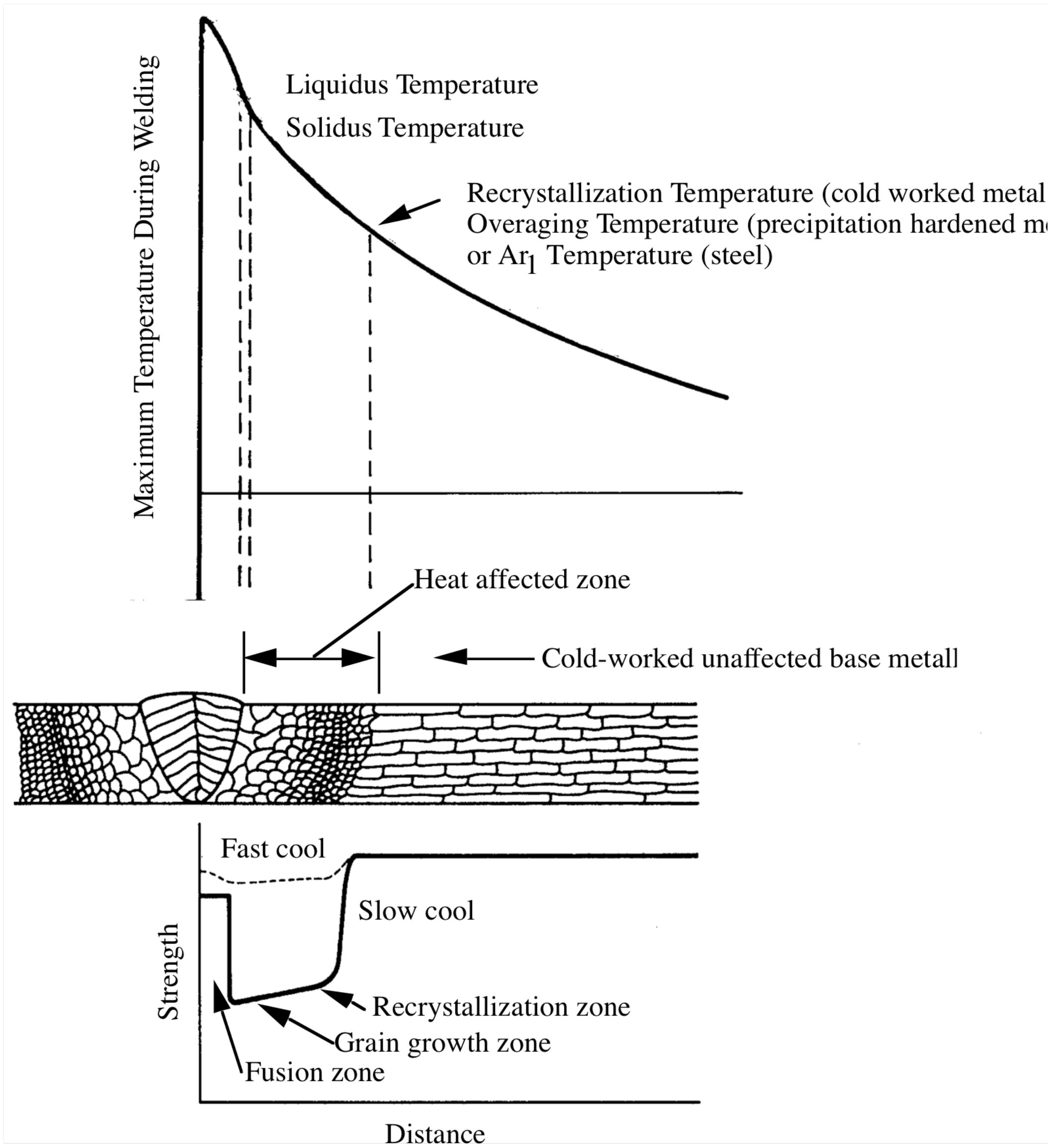


Figure 1. Structure and Properties Surrounding a Weld

steels, portions of the metal that are heated above the eutectoid transformation temperature (A_3) may form regions of martensite during subsequent cooling, provided the cooling rate is sufficient.

The thin layer of martensite in the HAZ is susceptible to fracture (i.e. low toughness), particularly if a lip is present on the weld to act as a stress concentrator.

V. Residual Stresses and Distortion

During the welding process, the weld and the surrounding metal are heated to high temperatures and allowed to cool. This localized heating and cooling cause uneven expansion and contraction of the workpiece, resulting in residual stresses and distortion (Figures 2 and 3).

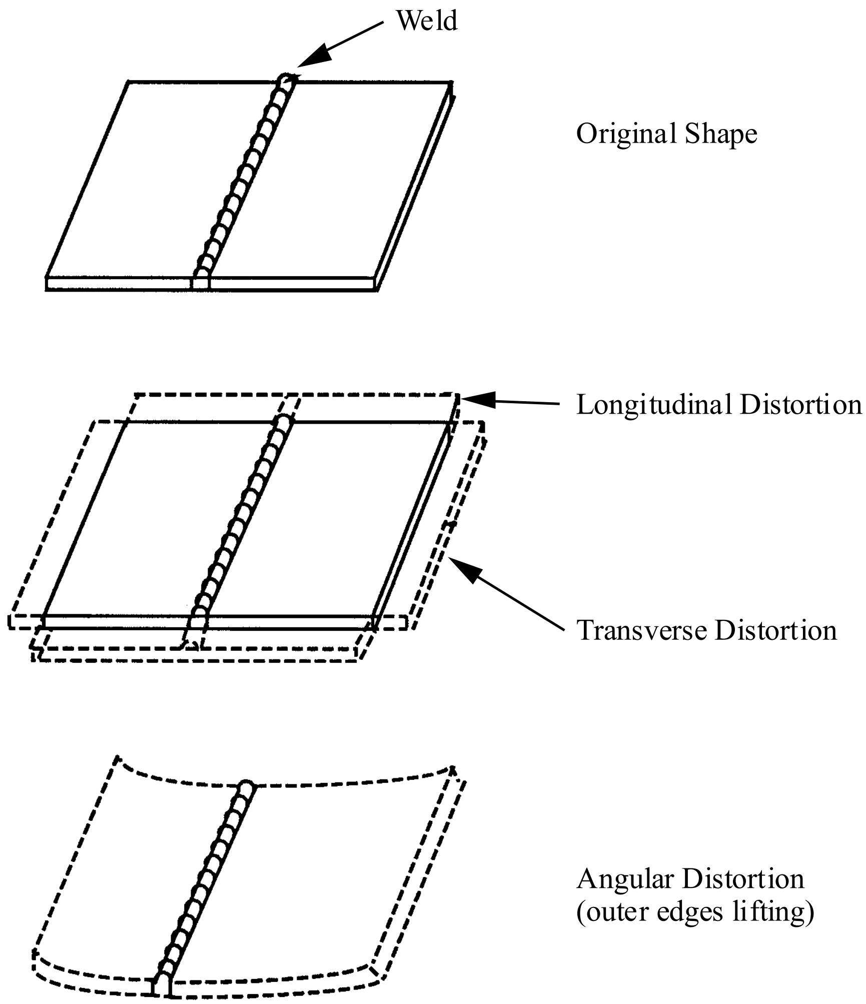


Figure 2. Distortion in a Welded Plate

As the weld pool solidifies, heat from the weld is dissipated to the plates. Thus, the plates begin to elongate while the weld begins to contract. However, the weld contraction will be constrained by the base metal, causing a residual tensile stress in the weld. The base metal will be pulled in by the contracting weld, resulting in a compressive stress in the base metal. The compressive stress must balance the tensile stresses in the weld for equilibrium. Depending on the magnitude of residual stresses in the structure, there will be a distortion. The distortion will cause the structure to bow in a concave direction with the weld on the inner surface of the bow. The material may accommodate the residual stresses by yielding if the stresses are high enough. However, reducing distortion by yielding is usually undesirable.

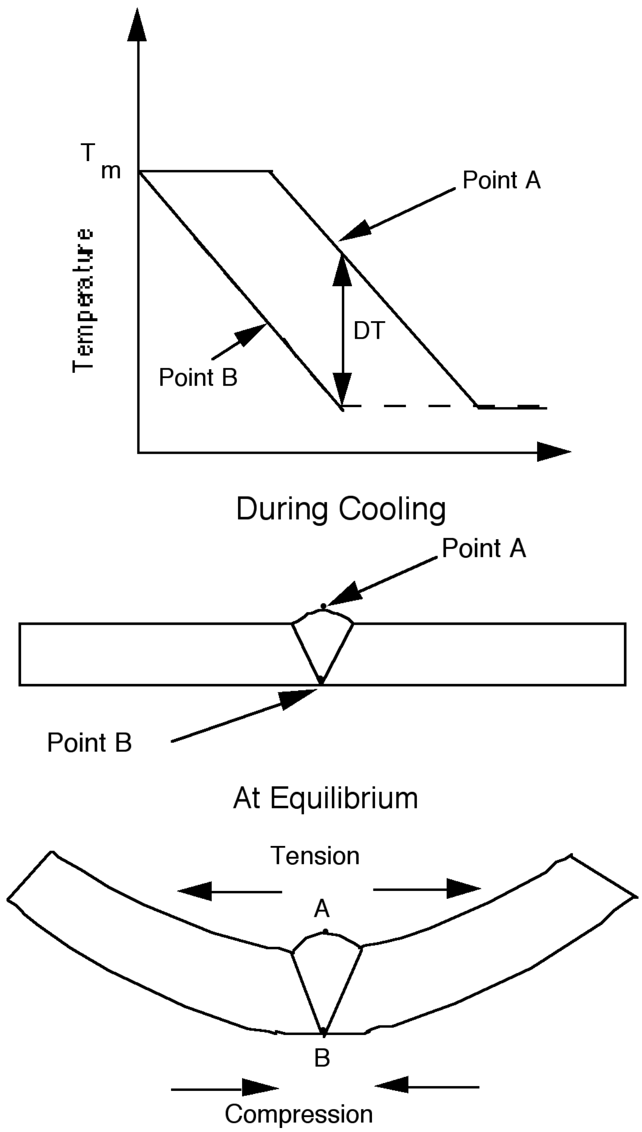


Figure 3. Weld Cooling and Deformation

In addition to distortion, residual stresses can cause other serious problems. For example, if part of a welded structure is removed by machining, the distortion may increase since the stresses are redistributed. The residual stresses may also cause stress-corrosion cracking. Additionally, the fatigue life of the welded component may be adversely affected. Generally, surface tensile residual stresses cause a decrease in fatigue life since cracks usually nucleate at the surface. Thus, it can be expected that fatigue life will decrease with residual stresses, although the effect of other possible defects and discontinuities in the weld may have a more pronounced effect.

There are several methods that can be used to control residual stresses and distortion. One method uses preheat, which decreases thermal gradients within the workpiece. Preheating reduces thermal expansion and contraction within the workpiece and thus, decreases the distortion. Alternatively, the component or structure may be stress-relieved at an appropriate temperature and for sufficient time after welding. Another method is to shot-peen the weld, which causes localized plastic deformation and introduces a compressive residual surface stress. However, shot-peening produces a surface finish that may be undesirable. Finally, restraining the weld as it cools can reduce distortion. Unfortunately, this restriction results in higher residual stresses.

VI. Experiments

In this laboratory, several welding specimens will be evaluated. The microstructure will be examined, and a hardness test in the region of the weld will be performed using a microhardness tester. Tensile tests will also be conducted to determine the strength of the welded joints.

A. Materials

The base material of the weld specimens may be either 1018 or 1045 steel, or a 6061 aluminum alloy. A schematic diagram of a specimen is shown in Figure 5. All specimens were welded with a gas-shielded wire feed welder in 50 cm plates, which were subsequently cut into 19 mm widths for tensile specimens. Some of the samples were chamfered for better weld penetration, which is the accepted technique when welding components together. Butt joints of two in-line plates are not common in practice. The goal in the lab is to show variation with penetration. Butt joints are common for the case of plates meeting at an angle. Some of the specimens have been welded poorly (this was done intentionally, and is called a "cold" weld) to demonstrate the effects of a low power welded joint. Standard ER70S-3 (steel) and 4043 (aluminum) wires were used as filler material. The various specimens have been labeled so that you will know what type is being tested.

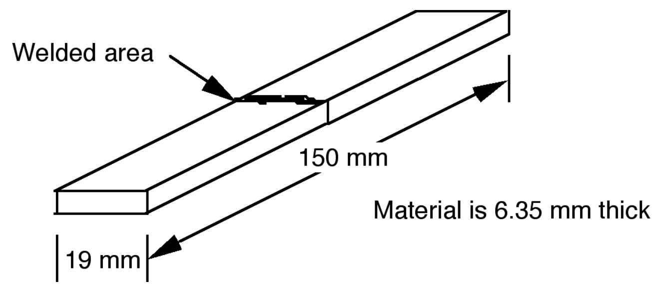


Figure 5. Weld Specimen Schematic

B. Procedures

(1) Measure base material dimensions as well as those required to determine the maximum cross sectional area of the weld. Record in Table 1. With a Sharpie marker make a line 45 mm from each end of the specimen and measure the distance between these lines (they will serve as a gage length for strain calculations). When mounting the specimen in the test frame, position the specimen so the lines align with the grip jaw end. Center the specimen in each grip back to front

(2) Perform tensile tests as directed on the two different materials and three different types of weld joints and weld power combinations (e.g., chamfer vs. butt joint; low vs. optimal weld power). Extensometers will not be utilized (utilize load and crosshead position on the computer display).

(3) Examine the fracture surface and measure any flaws (such as an incomplete penetration gap) that may have influenced the results. Also note where in the sample the failure occurred (base metal away from the weld, near the stress concentrator at the weld bead-base metal interface, or through the weld bead).

(4) Observe microhardness tests on samples that have been etched to reveal microstructures associated with welding. Several microstructures for the welds tested in this lab will be posted on the class web site. Using the video measurement system make selected measurements in the weld fusion zone, heat affected zone (HAZ), and base metal for both the aluminum and steel samples. A complete line traverse of hardness data will be available as a text file on the class data site.

(5) Watch the videotape presentations of welding processes if it was not shown in class.

References

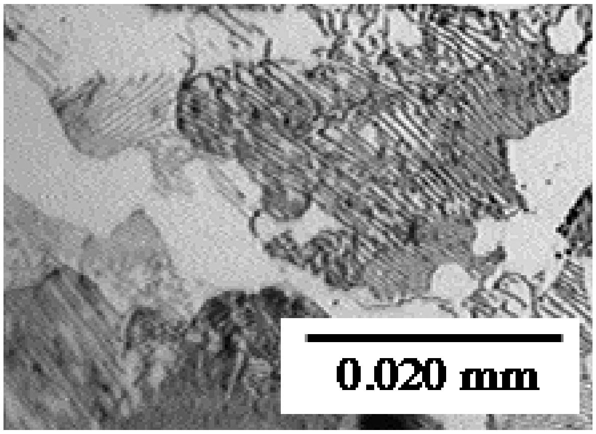
Callister, W.D., Jr., Materials Science and Engineering: An Introduction, Wiley, 1985, Chapter 11.

Flinn, R.A., and P.K. Trojan, Engineering Materials and Their Applications, Third Edition, Houghton Mifflin, 1986, Chapter 3.

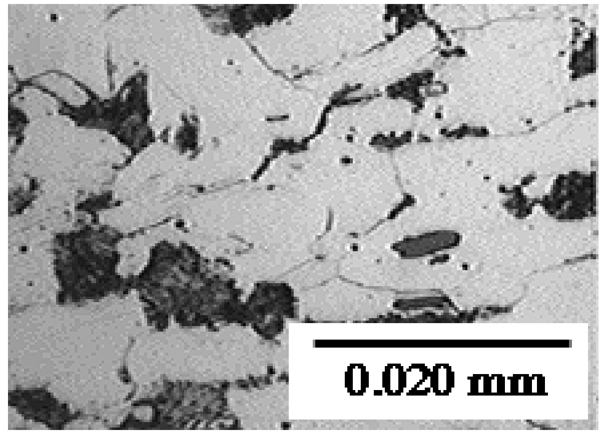
Kalpakjian, S., Manufacturing Processes for Engineering Materials, Addison-Wesley, 1984, Chapter 12.

Kou, S., Welding Metallurgy, Wiley-Interscience, 1987, Chapter 1.

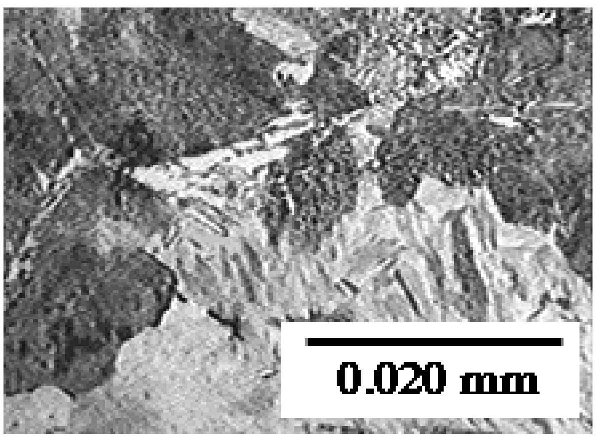
The Procedure Handbook of Arc Welding, 12th Edition, The Lincoln Electric Company, 1973.



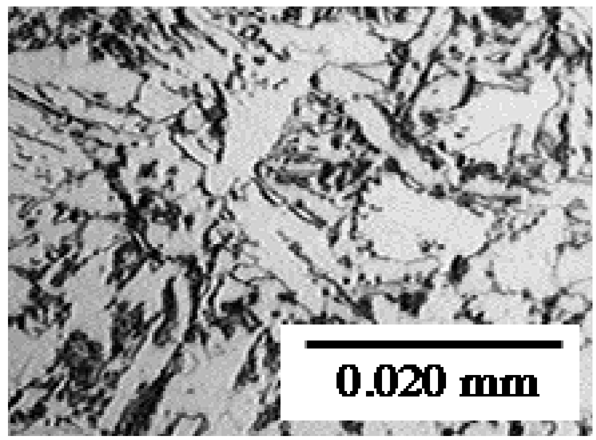
(a) 1045 base metal



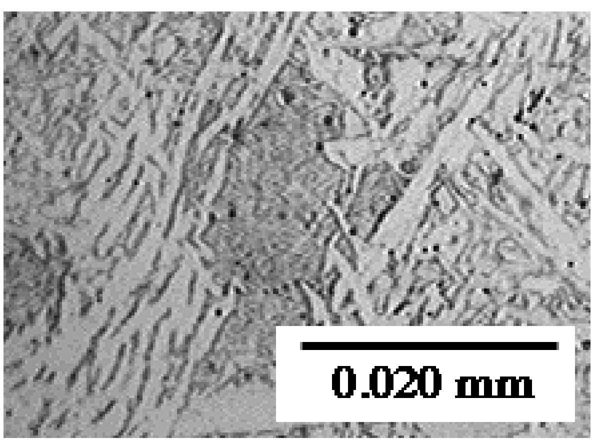
(b) 1018 base metal



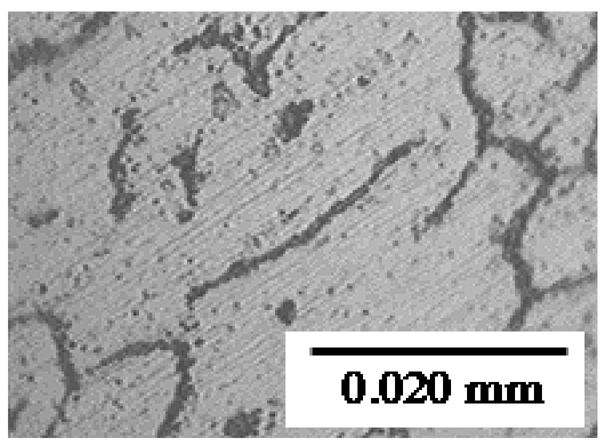
(c) 1045 HAZ



(d) 1018 HAZ



(e) Steel ER70S-3 weld metal



(f) Aluminum 4043 filler metal

Figure 7(a-f): Welding Microstructures

Table 1: Welded Tension Test Data

Measurement or Property			**Material / Weld Type**				
Quantity	*Symbol*	*Units*					
Specimen and Fixture Dimensions							
BM Rockwell Hardness							
Initial Width	W_o						
Initial Width	W_o						
Initial Width	W_o						
Initial Base Metal Thick	t						
Initial Base Metal Thick	t						
Initial Base Metal Thick	t						
Weld Thickness	t_w						
Weld Thickness	t_w						
Weld Thickness	t_w						
Gage Length	L_G						
Final Width	W_f						
Gap Thickness (unwelded)	t_g						
Failure Location (WM HAZ or BM)							
Crosshead Loading Rate	$d\delta/dt$						
Calculated Property							
Weld Metal Thickness ($t_w - t_g$)	t_{wm}						
Weld Metal Area	A_w						
Experimental Quantities							
Proportional Limit	P_y						
Offset yield Load	$P_{0.2\%y}$						
Maximum Load	P_{max}						
DATA FILENAME							

Table 2: Microhardness Data

Position (mm)	Microhardness Indent Size (mm)	Microstructure (WM HAZ or BM)
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CLASS MICROHARDNESS HARDNESS DATA FILENAME:__________________
Notes and sketches: