WLD 290
Submerged Arc Welding
Index

Course Information 3

SAW Information Sheets 4-21

Welding Work Sheets 22-42

Craftsmanship Expectations for Welding Projects 43

Welding Projects 44-45

Final Exam Information 46-50

Assessment Breakdown for the Course 51

Appendix 52

Supplemental Videos See Welding Resource Room
Course Assignments

This is a 200 level college course. Expect to do some research via internet, and other written materials to answer all the questions in this course.

Text Book Material

Lincoln Electric’s SAW CD Training Material
Welding Principles and Applications, by Larry Jeffus
AWS D1.1 Structural Welding Code – Steel

Reference Resources

Lincoln Electric’s Submerged Arc Welding Guide
Lincoln Procedure Handbook

Writing Work Sheets

Welding Projects

Final Exam

Part One (Closed Book Exam)
Part Two (Practical – Developing a welding procedure)

Timeline

The open-entry, open-exit instructional format allows the students to work at their own pace. It is the student’s responsibility to complete all assignments in a timely manner. See your instructor for assistance.

Outcome Assessment Policy

The student will be assessed on his/her ability to demonstrate the achievement of course outcomes. The methods of assessment may include one or more of the following: oral or written examinations, quizzes, written assignments, visual inspection techniques, welding tests, safe work habits, task performance and work relations.

Grading criteria:

The student's assessment will be based on the following criteria:
15% of grade is based on Safe work habits and shop practices.
20% of grade is based on Completion of written and reading assignments.
15% of grade is based on demonstrating professional work ethics (Habits).
40% of grade is based on completion of welding exercises.
10% of grade is based on final exam/project
**Submerged Arc Welding (SAW) Introduction**

From Wikipedia

Submerged Arc Welding (SAW) is a common arc welding process. It requires a continuously fed consumable electrode. The molten weld and the arc zone are protected from atmospheric contamination by being “submerged” under a blanket of granular fusible flux. When molten, the flux becomes conductive, and provides a current path between the electrode and the work.

SAW is normally operated in the automatic or mechanized mode, however, semi-automatic (hand-held) SAW guns with pressurized or gravity flux feed delivery are available. The process is normally limited to the 1F, 1G, or the 2F positions (although 2G position welds have been done with a special arrangement to support the flux). Deposition rates approaching 100 lb/h (45 kg/h) have been reported — this compares to 10 lb/h (5 kg/h) (max) for shielded metal arc welding. Currents ranging from 200 to 1500 amps are commonly used; currents of up to 5000 amps have been used (multiple arcs).

Material applications

- Carbon steels (structural and vessel construction);
- Low alloy steels;
- Stainless steels;
- Nickel-based alloys;
- Surfacing applications (wear facing, build-up, and corrosion resistant overlay of steels).

Advantages of SAW

- High deposition rates (over 100 lb/h (45 kg/h) have been reported);
- High operating factors in mechanized applications;
- Deep weld penetration;
- Sound welds are readily made (with good process design and control);
- High speed welding of thin sheet steels at over 100 in/min (2.5 m/min) is possible;
- Minimal welding fume or arc light is emitted.

Practically no edge preparation is necessary. The process is suitable for both indoor and outdoor works. Distortion is much less. Welds produced are sound, uniform, ductile, corrosion resistant and have good impact value. Single pass welds can be made in thick plates with normal equipment. The arc is always covered under a blanket of flux, thus there is no chance of spatter of weld.
## Limitations of SAW

- Limited to ferrous (steel or stainless steels) and some nickel based alloys;
- Normally limited to the 1F, 1G, and 2F positions;
- Normally limited to long straight seams or rotated pipes or vessels;
- Requires relatively troublesome flux handling systems;
- Flux and slag residue can present a health & safety issue;
- Requires inter-pass and post weld slag removal.

## Key SAW process variables

- Wire Feed Speed (main factor in welding current control);
- Arc Voltage;
- Travel Speed;
- Electrode Stick-Out (ESO) or Contact Tip to Work (CTTW);
- Polarity and Current Type (AC or DC).

## Other factors

- Flux depth/width;
- Flux and electrode classification and type;
- Electrode wire diameter;
- Multiple electrode configurations.

---

### Heat-affected zone

*From Wikipedia*

The cross-section of a welded butt joint, with the darkest gray representing the weld or fusion zone, the medium gray the heat affected zone, and the lightest gray the base material.

The **heat-affected zone** (HAZ) is the area of base material which has had its microstructure and properties altered by welding or heat intensive cutting operations. The heat from the welding process and subsequent re-cooling causes this change in the area surrounding the weld. The extent and magnitude of property change depends primarily on the base material, the weld filler metal, and the amount and concentration of heat input by the welding process.

The HAZ is an important aspect because cracking can occur in this zone. Underbead cracking is common in low alloy steels that have gone through some form of heat treating. Common steels in this category are A514 and A517 steels. These are also known as T1 Steel. When welding these steels it is important to select the correct flux and filler metal as well as have the correct heat input to prevent delayed cracking.
# SAW Introduction Questions

Name: ________________________________ Date:____________

Using the text book, Lincoln Electric Reference materials and /or the internet complete the following questions. Respond to questions using complete sentences.

1. What protects the molten SAW pool from the atmosphere?

2. How is the weld metal deposited in the molten weld pool of the SA welding process?

3. Why does a welder/operator not have to wear a welding helmet when using the SAW process?

4. List 5 materials that the SAW process can be used on
   
a. 
   
b. 
   
c. 
   
d. 
   
e. 

5. Define HAZ
6. Define thermal diffusivity and why is it important?

7. Using the AWS classification system for SAW electrodes, define the following
   
   Electrode  F5A2 - EH14

8. Using the AWS classification system for SAW flux, define the following flux type.
   
   F5A2 - EH14

9. Why are alloys not added to a fused flux

10. What is in bonded SA fluxes

11. List 6 advantages of SAW and 3 disadvantages.
12. Is weld spatter a factor in SAW? Why or Why not?

13. Define
   - ESO -
   - CTTW -

14. List 5 reasons why porosity would occur
   1. 
   2. 
   3. 
   4. 
   5. 

15. How much reused/recycled flux should be used in making a weld?
Weldability

*From Wikipedia*

The **weldability** of a material refers to its ability to be **welded**. Many metals and thermoplastics can be welded, but some are easier to weld than others. It greatly influences weld quality and is an important factor in choosing which welding process to use.

**Steels**

The weldability of **steels** is inversely proportional to a property known as the **hardenability** of the steel, which measures the ease of forming **martensite** during heat treatment. This means that the harder the material the more difficult it will be to weld because it will be more likely to crack.

The hardenability of steel depends on its chemical composition, with greater quantities of carbon and other **alloying** elements resulting in a **higher hardenability and thus a lower weldability**. In order to be able to judge alloys made up of many distinct materials, a measure known as the **equivalent carbon content** is used to compare the relative weldabilities of different alloys by comparing their properties to a plain **carbon steel**. The effect on weldability of elements like **chromium** and **vanadium**, while not as great as carbon, is more significant than that of **copper** and **nickel**, for example. As the equivalent carbon content rises, the weldability of the alloy decreases. The disadvantage to using plain carbon and low-alloy steels is their lower strength—there is a trade-off between material strength and weldability.

**High strength, low-alloy steels** were developed especially for welding applications during the **1970s**, and these generally easy to weld materials have good strength, making them ideal for many welding applications. Higher carbon steels, as well as alloys, may be successfully welded be utilizing preheat. As mentioned above carbon is a primary component

The American Welding Society (AWS) addresses this issue in their AWS D1.1 Structural Steel Welding Code (1996) Annex X14 Hydrogen Control. It is here where AWS gives an equation to compute the Carbon Equivalent of a material to determine the susceptibility towards cracking and further more what the preheat and interpass temperatures need to be.

\[ CE = \frac{Mn + Si}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \]

The chemical analysis to solve this equation may be obtained from:

1. Mill Tests
2. Typical production chemistry
3. Specification Chemistry
4. Users Test
Once the carbon equivalent is determined, the materials’ susceptibility to cracking is known. The welder fabricator can then reference the correct amount of preheat/interpass temperature to apply to the weldment prevent cracking.

Typical CE Values corresponding to preheat/interpass Temperature values

<table>
<thead>
<tr>
<th>Calculated Carbon Equivalent</th>
<th>Minimum Preheat Temperature in Fahrenheit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 0.40</td>
<td>70 F (ambient temperature)</td>
</tr>
<tr>
<td>0.40 to 0.45</td>
<td>100 F</td>
</tr>
<tr>
<td>0.45 – 0.55</td>
<td>200 F</td>
</tr>
<tr>
<td>0.55 – 0.65</td>
<td>200 – 300 F</td>
</tr>
<tr>
<td>0.65 – 0.75</td>
<td>300 – 400 F</td>
</tr>
<tr>
<td>0.75 and above</td>
<td>500 F</td>
</tr>
</tbody>
</table>
How Hot is Hot Enough?

A Primer on Weldment Preheating and Interpass Temperature

R. Scott Funderburk

Shops preheat weldments to slow the cooling rate to produce a more ductile metallurgical structure; allow any hydrogen present to diffuse out and reduce the potential for cracking; reduce shrinkage stresses in the weld and adjacent base material; and to help attain specific mechanical properties. Heed the following advice to know when and how to apply preheat.

To preheat prior to welding, an operator heats the base material, either in its entirety or just the region surrounding the weld joint to a specific temperature called the preheat temperature. He may continue to apply heat during welding, but often the heat from welding sufficiently maintains the desired temperature. The interpass temperature, defined as base-material temperature when welding is to be performed between the first and last passes, cannot be permitted to fall below the preheat temperature.

Preheating produces many benefits; however, without a working knowledge of the fundamentals involved, one risks wasting money or, even worse, degrading the integrity of the weldment.

Why preheat?

Shops apply preheat for four primary reasons:

- It slows the cooling rate in the weld and base material, producing a more ductile metallurgical structure with greater resistance to cracking.
- The slower cooling rate allows any hydrogen present to diffuse out harmlessly, reducing the potential for cracking.
- Preheat reduces shrinkage stresses in the weld and adjacent base material, particularly important in highly restrained joints.
- It raises some steels above the temperature at which brittle fracture would occur in fabrication. Additionally, preheat can help attain specific mechanical properties, such as notch toughness.

When to use preheat

To determine whether or not to preheat, engineers consider code requirements, section thickness, base-material composition, joint restraint, ambient temperature, filler-metal hydrogen content, and previous cracking problems. Welding codes typically specify the minimum preheat temperature for a given base material, welding process, and section thickness. The welder must attain this minimum value regardless of the restraint or variation in base-material composition. He may also increase the minimum value if necessary.

When welding without a governing code, the engineer must determine whether preheat is required, and if so, the appropriate preheat temperature. In general, preheat is usually not required on low-carbon steels less than 1 inch thick. However, as the diffusible-hydrogen level of the weld material, amount of restraint, or section thickness increase, the need for preheat rises.
How hot is hot enough?

Welding codes will also typically specify minimum values for preheat temperature, which may or may not be adequate to prohibit cracking in every application. For example, if a fabricator wishes to weld beam-to-column connections of ASTM A572-Grade 50 jumbo sections, with joint thickness ranging from 4 to 5 inches, with a low-hydrogen electrode, it must preheat to a minimum of 225 F, per AWS D1.1---Structural Welding Code---Steel. However, for making butt splices in jumbo sections, fabricators need to increase the preheat temperature beyond this minimum prequalified level, to around 350 F. This conservative recommendation acknowledges that the minimum preheat requirements prescribed by AWS D1.1 may not be adequate for highly restrained connections.

When welding without using the boundaries of a welding code, to determine an appropriate preheat temperature engineers can turn to AWS D1.1, Annex XI: "Guideline on Alternative Methods for Determining Preheat." This annex presents two procedures for establishing preheat temperature, developed primarily from laboratory-run cracking tests: one for hardness control of the heat-affected zone (HAZ), the other for hydrogen control. The HAZ hardness-control method, used only for fillet welds, assumes that cracking will not occur if the HAZ hardness stays below some critical value. This is achieved by controlling cooling rate—the critical cooling rate for a given hardness can be related to the carbon equivalent of the steel. From the critical cooling rate, a minimum preheat temperature can then be calculated. AWS D1.1 states that, "Although the method can be used to determine a preheat level, its main value is in determining the minimum heat input (and hence minimum weld size) that prevents excessive hardening."

The hydrogen-control method described in the D1.1 Annex XI assumes that cracking will not occur if the amount of hydrogen remaining in the joint after it has cooled to about 120 F does not exceed a critical value dependent on the composition of the steel and the level of restraint. This procedure is extremely useful for high-strength low-alloy steels with high hardenability. However, the calculated preheat may be somewhat conservative for carbon steels.

The three basic steps of the hydrogen-control method:

- Calculate a composition parameter similar to the carbon equivalent
- Calculate a susceptibility index as a function of the composition parameter and the filler-metal diffusible-hydrogen content
- Determine the minimum preheat temperature from the restraint level, material thickness, and susceptibility index.

**Torch it**

Selecting a method for applying preheat, consider material thickness, weldment size, and available heating equipment. A furnace might work best for heating small production assemblies, while preheating large structural components might require banks of torches, electrical strip heaters, or induction or radiant heaters.

Preheating carbon steel to a precise temperature is not typically required—fabricators can usually exceed the required minimum preheat temperature by 100 F or so. However, when welding some quenched-and-tempered steels such as A514 or A517, operators must closely follow the established maximum and minimum preheat temperatures in order to ensure adequate mechanical properties in the HAZ.

When heating the weld joint and surrounding base material, AWS D1.1 requires that the operator establish the minimum preheat temperature at a distance from the joint at least equal to the thickness of the thickest member, but not less than 3 inches in all directions from the point of welding. To ensure that the full material volume surrounding the joint is heated, the operator should heat the side opposite of that which is to be welded and measure the surface temperature.
adjacent to the joint. Finally, he should check interpass temperature to verify that he has maintained the minimum preheat temperature just prior to initiating the arc for each pass.

**The importance of interpass temperature**

To control the mechanical and micro structural properties of weldments, interpass temperature is just as important as, if not more important than, preheat temperature. Yield and ultimate tensile strengths of the weld metal depend greatly on interpass temperature. A high interpass temperature can reduce weld strength and at the same time result in a finer grain structure and improved Charpy V notch-toughness transition temperatures. However, when interpass temperatures exceed approximately 500 F, this trend is reversed. In fact, the American Welding Society *Position Statement on the Northridge Earthquake* recommends that interpass temperature not exceed 550 F when notch toughness is a requirement.

There are other times when a designer may want to limit the maximum interpass temperature. For example, if he expects a minimum strength level for a particular component that could experience extremely high interpass temperatures, due to its size or welding procedures, he would specify a maximum interpass temperature. Otherwise, weld strength may be unacceptably low. A maximum interpass temperature is also necessary for quenched and tempered steels. Due to their heat treating characteristics, engineers must control interpass temperature within limits in order to provide adequate mechanical properties in the weld metal and HAZ.

Maximum interpass temperature control is not always required. In fact, AWS D1.1 does not impose such control.

**A delicate balance**

Particularly on sensitive base materials, an engineer needs to specify a minimum interpass temperature to prevent cracking, and a maximum interpass temperature in order to provide adequate mechanical properties. To maintain this balance, he considers the time between passes, base-material thickness, preheat temperature, ambient conditions, heat transfer characteristics, and heat input from welding.

Weldments with smaller cross-sectional areas naturally tend to “accumulate” interpass temperature: as welding continues, the temperature of the part increases. A general rule: If the cross-sectional area is less than 20 in.$^2$, interpass temperature will tend to increase with each sequential weld pass under normal production rates. However, if the cross-sectional area is greater than 40 in.$^2$, interpass temperature decreases throughout the welding sequence unless the operator applies an external heat source.

**Measurement and control of interpass temperature**

One way to monitor and control interpass temperature is to use temperature-indicating crayons. A surface-applied temperature-indicating crayon melts when the weldment reaches the crayon's melting temperature. Available in a variety of melting temperatures, each crayon is labeled with its approximate melting point. Welders can use one temperature-indicating crayon to measure the minimum specified preheat and interpass temperatures, then use a second higher-temperature crayon to monitor interpass temperature, if required.

The operator first heats the weld joint and checks base-material temperature at the code-designated location by marking the base material with the first temperature-indicating crayon. When he attains the minimum specified preheat temperature, as indicated by the melting of the first crayon mark, he can then begin depositing the first welding pass.
Immediately before the second and subsequent passes, he applies crayon marks to verify attainment of the minimum and maximum (if specified) interpass temperatures. The lower-temperature crayon should melt, indicating that the temperature of the base material exceeds the melting temperature of the crayon, while the higher-temperature crayon should not melt, indicating that base-material temperature registers below the maximum interpass temperature.

If the lower-temperature crayon does not melt, the welder must apply additional heat to the joint until the crayon mark does melt. Too, if the higher-temperature crayon melts, the welder should allow the joint to cool slowly in the ambient air until the crayon mark no longer melts, while still being sure that the lower-temperature crayon does melt. Only then should he begin the next pass.

**Location, location, location**

Codes and industry standards specify where on a weldment operators should check interpass temperature. AWS D1.1 *Structural Welding Code - Steel* and D1.5 *Bridge Welding Code* require that the interpass temperature be maintained "for a distance at least equal to the thickness of the thickest welded part (but not less than 3 inches) in all directions from the point of welding." This makes sense, and is conservative when controlling minimum interpass temperature. However, in cases requiring control of maximum interpass temperature, the actual interpass temperature in the HAZ may significantly exceed the maximum specified interpass temperature. Here, the operator should measure the temperature 1 inch from the weld toe.

In other cases, specific industries have adopted self-imposed regulations. For example, one shipyard I know of maintains interpass temperature 1 inch from the weld toe and within the first 12 inches of its start. Operators apply preheat from the back side of the joint so as to completely "soak" the base material.

Although there is some debate as to where to measure interpass temperature, most experts agree that it must be maintained for some reasonable distance away from the welded joint. Since this decision may greatly influence fabrication costs, fabricators must determine a reasonable and practical location. One foot away from the joint is probably excessive, while a tenth of an inch, or on the weld itself, is not right either. One inch from the weld toe seems appropriate.

*Welding Design & Fabrication, a Penton Media, Inc. publication. May 1999*
Strength of Materials

From Wikipedia

Strength is considered in terms of compressive strength, tensile strength, and shear strength, namely the limit states of compressive stress, tensile stress and shear stress, respectively. The effects of dynamic loading is probably the most important practical part of the strength of materials, especially the problem of fatigue. Repeated loading often initiates brittle cracks, which grow slowly until failure occurs.

Definitions

Stress terms

A material being loaded in a) compression, b) tension, c) shear.

- **Compressive stress** (or compression) is the stress state when the material (compression member) tends to compact. A simple case of compression is the uniaxial compression induced by the action of opposite, pushing forces. Compressive strength for materials is generally higher than that of tensile stress, but geometry is very important in the analysis, as compressive stress can lead to buckling.

- **Tensile stress** is a loading that tends to produce stretching of a material by the application of axially directed pulling forces. Any material which falls into the "elastic" category can generally tolerate mild tensile stresses while materials such as ceramics and brittle alloys are very susceptible to failure under the same conditions. If a material is stressed beyond its limits, it will fail. The failure mode, either ductile or brittle, is based mostly on the microstructure of the material. Some Steel alloys are examples of materials with high tensile strength.

- **Shear stress** is caused when a force is applied to produce a sliding failure of a material along a plane that is parallel to the direction of the applied force. An example is cutting paper with scissors.
Strength Terms

- **Yield strength** is the lowest stress that gives permanent deformation in a material. In some materials, like aluminum alloys, the point of yielding is hard to define, thus it is usually given as the stress required to cause 0.2% plastic strain.

- **Compressive strength** is a limit state of compressive stress that leads to compressive failure in the manner of ductile failure (infinite theoretical yield) or in the manner of brittle failure (rupture as the result of crack propagation, or sliding along a weak plane - see shear strength).

- **Tensile strength** or ultimate tensile strength is a limit state of tensile stress that leads to tensile failure in the manner of ductile failure (yield as the first stage of failure, some hardening in the second stage and break after a possible "neck" formation) or in the manner of brittle failure (sudden breaking in two or more pieces with a low stress state). Tensile strength can be given as either true stress or engineering stress.

Strain (deformation) terms

- **Deformation** of the material is the change in shape (geometry) when stress is applied (in the form of force loading).

- **Strain** or reduced deformation is a mathematical term to express the trend of the deformation change among the material field. For uni-axial loading - displacements of a specimen (for example a bar element) it is expressed as the quotient of the displacement and the length of the specimen. For 3D displacement fields it is expressed as derivatives of displacement functions in terms of a second order tensor (with 6 independent elements).

- **Deflection** is a term to describe the magnitude to which a structural element bends under a load.

Stress-strain relations

Stress is the load measured in pounds. In other words it’s the force it takes to pull apart the tensile specimen.

- **Elasticity** is the ability of a material to return to its previous shape after stress is released – like a rubber band. In many materials, the relation between applied stress and the resulting strain is directly proportional (up to a certain limit), and a graph representing those two quantities is a straight line.

The slope of this line is known as Young’s Modulus, or the "Modulus of Elasticity." The Modulus of Elasticity can be used to determine stress-strain relationships in the linear-elastic portion of the stress-strain curve. The linear-elastic region is taken to be between 0 and 0.2% strain, and is defined as the region of strain in which no yielding (permanent deformation) occurs.
Plasticity or plastic deformation (the material stretches and stays in that shape) is the opposite of elastic deformation and is accepted as unrecoverable strain. Plastic deformation is retained even after the relaxation of the applied stress. Most materials in the linear-elastic category are usually capable of plastic deformation. Brittle materials, like ceramics, do not experience any plastic deformation and will fracture under relatively low stress. Materials such as metals usually experience a small amount of plastic deformation before failure while soft or ductile polymers will plastically deform much more.

Consider the difference between a fresh carrot and chewed bubble gum. The carrot will stretch very little before breaking, but nevertheless will still stretch. The chewed bubble gum, on the other hand, will plastically deform enormously before finally breaking.

**Tensile Strength**

*From Wikipedia*

**Tensile strength** measures the stress required to pull something such as rope, wire, or a structural beam to the point where it breaks.

Explanation

The tensile strength of a material is the maximum amount of tensile stress that it can be subjected to before failure. The definition of failure can vary according to material type and design methodology. This is an important concept in engineering, especially in the fields of material science, mechanical engineering and structural engineering.

There are three typical definitions of tensile strength:

- **Yield strength**: The stress at which material strain changes from elastic deformation to plastic deformation, causing it to deform permanently.

- Ultimate strength: The maximum stress a material can withstand.

- Breaking strength: The stress coordinate on the stress-strain curve at the point of rupture.
Concept

The various definitions of tensile strength are shown in the following stress-strain graph for low-carbon steel:

Stress vs. Strain curve typical of structural steel
1. Ultimate Strength
2. Yield Strength
3. Rupture
4. Strain hardening region
5. Necking region.

Metals including steel have a linear stress-strain relationship up to the yield point, as shown in the figure. In some steels the stress falls after the yield point. This is due to the interaction of carbon atoms and dislocations in the stressed steel. Cold worked and alloy steels do not show this effect. For most metals yield point is not sharply defined. Below the yield strength all deformation (stretching) is recoverable, and the material will return to its initial shape when the load is removed (elastic). For stresses above the yield point the deformation is not recoverable, and the material will not return to its initial shape. This unrecoverable deformation is known as plastic deformation. For many applications plastic deformation is unacceptable, and the yield strength is used as the design limitation.

After the yield point, steel and many other ductile metals (ability to stretch without breaking) will undergo a period of strain hardening, in which the stress increases again with increasing strain up to the ultimate strength. If the material is unloaded at this point, the stress-strain curve will be parallel to that portion of the curve between the origin and the yield point. If it is re-loaded it will follow the unloading curve up again to the ultimate strength, which has become the new yield strength.
After a metal has been loaded to its yield strength it begins to "neck" as the cross-sectional area of the specimen decreases due to plastic flow. When necking becomes substantial, it may cause a reversal of the engineering stress-strain curve, where decreasing stress correlates to increasing strain because of geometric effects. This is because the engineering stress and engineering strain are calculated assuming the original cross-sectional area before necking. If the graph is plotted in terms of true stress and true strain the curve will always slope upwards and never reverse, as true stress is corrected for the decrease in cross-sectional area. Necking is not observed for materials loaded in compression. The peak stress on the engineering stress-strain curve is known the ultimate tensile strength. After a period of necking, the material will rupture and the stored elastic energy is released as noise and heat. The stress on the material at the time of rupture is known as the breaking stress.

Ductile metals do not have a well defined yield point. The yield strength is typically defined by the "0.2% offset strain". The yield strength at 0.2% offset is determined by finding the intersection of the stress-strain curve with a line parallel to the initial slope of the curve and which intercepts the abscissa at 0.002. A stress-strain curve typical of aluminum along with the 0.2% offset line is shown in the figure below.

Brittle materials such as concrete and carbon fiber do not have a yield point, and do not strain-harden which means that the ultimate strength and breaking strength are the same. A most unusual stress-strain curve is shown in the figure below. Typical brittle materials do not show any plastic deformation but fail while the deformation is elastic. One of the characteristics of a brittle failure is that the two broken parts can be reassembled to
produce the same shape as the original component. A typical stress strain curve for a brittle material will be linear. Testing of several identical specimens will result in different failure stresses. The curve shown below would be typical of a brittle polymer tested at very slow strain rates at a temperature above its glass transition temperature. Some engineering ceramics show a small amount of ductile behavior at stresses just below that causing failure but the initial part of the curve is a linear.

**Typical Tensile Strengths**

Some typical tensile strengths of some materials:

<table>
<thead>
<tr>
<th>Material</th>
<th>Yield strength (MPa)</th>
<th>Ultimate strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural steel ASTM A36 steel</td>
<td>250</td>
<td>400</td>
</tr>
<tr>
<td>Steel, high strength alloy ASTM A514 (Known as T01)</td>
<td>690</td>
<td>760</td>
</tr>
<tr>
<td>Stainless steel AISI 302 - Cold-rolled</td>
<td>520</td>
<td>860</td>
</tr>
<tr>
<td>Cast iron 4.5% C, ASTM A-48</td>
<td>276 (??)</td>
<td>200</td>
</tr>
<tr>
<td>Aluminum Alloy 2014-T6</td>
<td>400</td>
<td>455</td>
</tr>
<tr>
<td>Tungsten</td>
<td>1510</td>
<td>19.25</td>
</tr>
</tbody>
</table>

**Tensile Stress**

*From Wikipedia*

Tensile stress (also referred to as normal stress or tension) is the stress state leading to expansion; that is, the tensile stress may be increased until the reach of tensile strength, namely the limit state of stress.

The formula for computing the tensile stress in a rod is:

\[ \sigma = \frac{F}{A} \]

where \( \sigma \) is the tensile stress, \( F \) is the tensile force over the rod and \( A \) is the cross-sectional area of the rod.

Units for tensile stress are pounds per square inch (psi). \( \sigma \) is positive for tensile stress while it is negative for compressive stress, regardless of force's direction.

Many of the mechanical properties of a material can be extracted from a tensile test. In a tensile test, a sample is strained at a constant rate and the stress needed to maintain this strain rate is measured. The stress and strain can either be measured in terms of engineering stress and strain or true stress and strain. The elastic modulus, the ultimate
tensile stress, the fracture stress, the modulus of toughness, and the modulus of resilience can all be determined from a tensile test. This will be important because you will be required to complete a tensile test when you develop a Procedure Qualification Record (PQR) in this class.
Common SAW Vocabulary

Define the following term.

1. Amperage

2. Arc Length

3. As-welded

4. Arc voltage

5. Base Material

6. Burnback

7. Complete Joint Penetration

8. Concavity (in fillet welds)
9. Convexity (in fillet welds)

10. Deposition Rate

11. Electrode Extension.

12. Granular flux

13. Heat Affected Zone (HAZ)

14. Hot Crack

15. Interpass Temperature

16. Longitudinal Crack

17. Over Lap
18. Overlaying

19. Preheat Temperature

20. Procedure Qualification Record (PQR)-

21. Stickout

22. Submerged Arc Welding (SAW)

23. Surface Preparation

24. Welding Procedure Specification

25. Worm Tracking

26. Stress (as it relates to tensile testing)
27. Strain (as it relates to tensile testing)

28. Elasticity

29. Plastic Deformation

30. Weldability

31. PSI

32. KSI
Welding Procedure Specification

From Wikipedia

A **Welding Procedure Specification** (WPS) is a formal document describing welding procedures. It is similar to a recipe for a chef.

According to the [American Welding Society](https://www.aws.org) (AWS), a WPS provides in detail the required welding variables for specific application to assure repeatability by properly trained welders and welding operators.

The American Society for Mechanical Engineers (ASME) similarly defines Welding Procedure Specification (WPS) as a written document that provides direction to the welder or welding operator for making production welds in accordance with Code requirements.

See Appendix 1 for a sample WPS included in this training packet.
**Welding Procedure Questions**

Name: _________________________________  Date: ____________

Using Appendix I in this training packet, what information goes in the following sections.

1. _____________________________________________________________________

12. _____________________________________________________________________

19. _____________________________________________________________________

25. _____________________________________________________________________

36. _____________________________________________________________________

38. _____________________________________________________________________

42. _____________________________________________________________________

43. _____________________________________________________________________

44. _____________________________________________________________________

45. _____________________________________________________________________
Welding Inspection Tools

The following section is designed to give the student a brief overview of common welding inspection tools. Review the information and be sure to see your instructor for questions.

You will be using these tools when you develop a welding procedure specification (WPS) for the final project.

Standard Ruler

[Diagram of a standard ruler with measurements labeled in inches: 0, 1/64, 1/32, 1/16, 1/8, 1/4, 1/2, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, 11.0, 12.0, 13.0, 14.0, 15.0, 16.0, 17.0, 18.0, 19.0, 20.0, 21.0, 22.0, 23.0, 24.0, 25.0, 26.0, 27.0, 28.0, 29.0, 30.0, 31.0, 32.0. All dimensions in inches.]
Standard Micrometer

Parts of a Micrometer
**AWS Tool Kit**

Zeroing the “Mike”

1) run to zero
2) if not zero, loosen set screw
3) adjust thimble until zero
4) tighten (not too tight) – recheck measurement calibration

**Reading a “Mike”**

.001 = thousandths
Thimble = 25 .00 graduations
Barrel = graduations of .025 (25 thousandths) –AND- graduations of .10 (tenths)
THIMBLE

NOTE:
EACH MARK ON THIMBLE EQUALS 1/1000

.001"

THIMBLE

(5 x .001 = .005")

.005"

SLEEVE

EACH MARK ON BARRELL EQUALS .025" (1ST MARK)

.025"

(D)

4 x .025 = .1

.100"
(A) Each mark on sleeve equals 0.025

(B) Thimble, each mark = 0.001

(C) 

(D) 

(E) 

(F) 

(G) 

(H)
ANSWERS

(A)


(A)


(B)


(B)


(C)


(C)


(D)


(D)
Metric Dial Caliper

Dial Caliper:

Parts:

1. Main Beam (10mm increments)
2. Slider
3. Dial (0.1mm increments)
4. Bezel (Movable Rim of Dial for zeroing)
5. Inside Jaws
6. Outside Jaws
7. Thumb wheel (for moving slider)
8. Depth Indicator

Reading Calipers:

1. Place calipers on piece to measure
2. Tighten snugly
3. Read “Main Beam” for graduation of 10mm
4. Read Dial for graduation less than 10 (i.e. – example in text)
Visual Inspection Work Sheet

NAME: ____________________    DATE: ________________

1. What is the measurement of the cross hatched object below?
   a. 1 23/32”
   b. 1 23/64”
   c. 2 5/32”
   d. 2 21/64”

2. Convert the answer from 1 above to millimeters using 1 inch equals 25.4 mm
   ______________

3. What is the measurement indicated on the instrument below?
   a. 0.752”
   b. 0.762”
   c. 0.747”
   d. 0.672”

4. Convert the answer from 3 above to millimeters using 1 inch equals 225.4 mm
   ______________

5. What is the measurement indicated on the instrument below?
   a. 10.87
   b. 15.78
   c. 18.70
   d. 78.70
6. Convert the answer from 5 above to inches using 1 inch equals 254 mm. 

7. Convert the answer from 5 above to the nearest 1/64” _______________

8. What is the size of the item being measured with the machinist’s ruler shown in the sketch below?

   ![Machinist's Ruler Image]

   a. 1-23/32 in.
   b. 1-23/64 in
   c. 1-21/64 in.
   d. 1-21/32 in.
   e. none of the above

9. A micrometer is being used to measure the width of a rectangular tensile specimen. What is its dimension if the micrometer appears as shown below?

   ![Micrometer Image]

   a. 0.658 in.
   b. 0.568 in.
   c. 0.762 in.
   d. 0.678 in.
   e. none of the above
10. The dial caliper is being used to measure the thickness of the rectangular tensile specimen in the question above. What is its dimension if the dial caliper appears as shown below?

![Dial Caliper Image]

a. 18.90 mm  
b. 10.87 mm  
c. 187.0 mm  
d. 18.70 mm  
e. none of the above

11. What is the calculated area of the tensile bar measured above?

a. 0.777 in$^2$ and 501.29 mm$^2$  
b. 0.555 in$^2$ and 358.06 mm$^2$  
c. 0.738 in$^2$ and 476.13 mm$^2$  
d. 0.561 in$^2$ and 361.85 mm$^2$  
e. none of the above

12. If the tensile specimen above failed at a load of 51,550 pounds, what is the ultimate tensile strength of this metal?

a. 91,890 psi  
b. 82,800 psi  
c. 66,400 psi  
d. 37,000 psi  
e. none of the above
13. Given the following information, calculate:

   a) UTS
   b) % Elongation
   c) % Reduction of Area

A tensile sample was tested and failed at 23,015 pounds of force. The original dimensions were: Thickness = .367” and the Width = .875”. The sample was marked for elongation and the distance between the center punch marks equaled 2.07 inches. After fracture, the 2 pieces were placed together and the final length = 2.79 inches. The final width = .603 inches and thickness = .187 inches.

14. Given the following information, determine/calculate the UTS.

   Round Tensile specimen / diameter = .605 inches (measured)

   Load = 13493 pounds to break sample

15. A weld is called out on the blueprint to be 205 mm. How long is that weld in terms of inches?

16. Convert a wire feed speed of 125 in/min to SI units (mm/second).
17. Convert -475°F to Celsius.

18. On the blueprint it calls for a 3/8 “fillet weld”, but this is what the welder produced.
   (Above)
   
   A. This is acceptable for the hands on code.
   B. This is not acceptable even for the hands-on code.
   C. The blueprint must be wrong.
   D. All of the above.

19. For the plate above, how has it been prepared?
   
   A. 53 degree angle.
   B. 37 degree included angle.
   C. 37 degree bevel angle.
   D. One must see the other half of the weld joint.
   E. This is a single-v joint.

20. Find the size of the box to the nearest 1/32” report both width and thickness.
   
   A. Width __________ B. Thickness ___________
21. For the tensile test below, determine the percent elongation.

The percent elongation is ________________
**SAW Projects**

Submerged Arc Welding is a fully automatic welding process. It is important that the student reviews Lincoln’s CD materials. The student will also need to review Lincoln’s *Submerged Arc Welding Guide* C5.50. This guide covers the following information:

- How to make a single electrode submerged arc weld
  - Cleanliness
  - Joint Design and Fit-up
  - Flux Coverage
  - Work Position
  - Flux and Electrode Selection
  - Preheat
  - Current (Wire Feed Speed = WFS)
  - Travel Speed
  - Voltage

The student will need to pay special attention the section titled: *Making Submerged Arc Welding in the Flat and Horizontal Positions*. It is here where the student will find the necessary information in conjunction with the project sheet to make a successful weld.

**AWS D1.1 Structural Welding Code – Steel**

In addition to the information above, the student will need to review the AWS D1.1 Code to find information regarding pre-qualified joints and their designation definitions. The student will need to familiarize themselves with this information since the welding projects joint design will be based on this designation system. Review the chapter 3 Pre-qualification of WPS’s.
**SAW Project #1**

Use Lincoln's Submerged Arc Welding Guide – Fillet Welds. Sketch the cross section of a single pass horizontal T-Joint that is made of the following material size: ½”x 4”x 4”. Two pieces are required and each piece will be 18 inches in length.

---

**Preparation of Base Metal**

Using OAC method cut the needed material and then remove all mill scale and slag.

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Welding Power</th>
<th>Flux Type</th>
<th>Base Metal Type</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>L61 EM14K</td>
<td>3/32” 500</td>
<td>35 860</td>
<td>A36 F7A2</td>
<td>½”</td>
</tr>
</tbody>
</table>

**Electrode**

**Welding Power**

**Flux**

**Type**

**Base Metal Type**

**Thickness**

- Polarity DCRP
- Travel Angle CTTWD
- Work Angle
- Travel Speed 24 IPM

**Preheat and Interpass Temperature:** 70 F

**Cleaning**

Clean each pass with mechanical tools to ensure all slag and potential discontinuities are removed.

**Final Inspection**

Using the AWS welding inspection tool kit, evaluate the entire length of the weld to determine if it meets the requirements set forth in AWS D1.1 Welding operator Qualification section.

<table>
<thead>
<tr>
<th>Cracks</th>
<th>Acceptable</th>
<th>Not Acceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Craters are filled</td>
<td>Acceptable</td>
<td>Not Acceptable</td>
</tr>
<tr>
<td>Overlap</td>
<td>Acceptable</td>
<td>Not Acceptable</td>
</tr>
<tr>
<td>Weld Reinforcement (flush to 1/8” max)</td>
<td>Acceptable</td>
<td>Not Acceptable</td>
</tr>
<tr>
<td>Undercut (max 1/32”)</td>
<td>Acceptable</td>
<td>Not Acceptable</td>
</tr>
<tr>
<td>Weld merges smoothly with base material</td>
<td>Acceptable</td>
<td>Not Acceptable</td>
</tr>
</tbody>
</table>
SAW Project #2

Using AWS D1.1, sketch the cross section of a BU2-S Joint (see index for prequalified joint details to determine location in code).

Using 1 inch plate, prepare material to be welded making the plates 4” wide by 18” long. Also prepare a back strap that’s 1/2” x 2” x 22”.

Preparation of Base Metal
Using OAC method cut the needed material and then remove all mill scale and slag.

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Welding Power</th>
<th>Flux</th>
<th>Base Metal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Size</td>
<td>Amps</td>
<td>Volts Type</td>
</tr>
<tr>
<td>L61 EM14K</td>
<td>3/32”</td>
<td>500</td>
<td>35 860 F7A2</td>
</tr>
<tr>
<td>ESO</td>
<td>CTTWD</td>
<td></td>
<td>Polarity DCRP</td>
</tr>
<tr>
<td>Travel Angle 90</td>
<td>Work Angle 90</td>
<td></td>
<td>Travel Speed 24 IPM</td>
</tr>
</tbody>
</table>

Preheat and Interpass Temperature: 150 F

Cleaning
Clean each pass with mechanical tools to ensure all slag and potential discontinuities are removed.

Final Inspection
Using the AWS welding inspection tool kit, evaluate the entire length of the weld to determine if it meets the requirements set forth in AWS D1.1 Welding operator Qualification section.

<table>
<thead>
<tr>
<th>Cracks</th>
<th>Acceptable</th>
<th>Not Acceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Craters are filled</td>
<td>Acceptable</td>
<td>Not Acceptable</td>
</tr>
<tr>
<td>Overlap</td>
<td>Acceptable</td>
<td>Not Acceptable</td>
</tr>
<tr>
<td>Weld Reinforcement (flush to 1/8” max)</td>
<td>Acceptable</td>
<td>Not Acceptable</td>
</tr>
<tr>
<td>Undercut (max 1/32”)</td>
<td>Acceptable</td>
<td>Not Acceptable</td>
</tr>
<tr>
<td>Weld merges smoothly with base material</td>
<td>Acceptable</td>
<td>Not Acceptable</td>
</tr>
</tbody>
</table>
Final Exam Part One

This portion of the final exam is a closed book test. Consult with your instructor to determine items that you may need to review. Once you determine that you are ready for the exam, see your instructor. Once completed, return the exam to your instructor.

Study Guide

Safety
- Oxyacetylene safety
- SAW safety
- Hand Tool Safety

SAW and OAC Processes
- Power source specifics
  - Polarity
  - Current output
- AWS electrode and flux classification
- OAC
  - Theory of cutting
  - Flame types
  - Safety

Welding Symbols and Blueprints
- Orthographic and Isometric views
- Welding symbol
  - Weld symbols
  - Reference line
  - Tail

Math and Math conversions
- Adding and subtracting fractions
- Reading a measurement instruments
- Metric conversions
Develop a WPS for a Single V-Groove Weld and complete the following mechanical tests listed in the WPS below.

**SAW Welding Procedure Specification**

**Welding Procedure Specification No.: _______________ Date: ______________**

**Title: Square Groove Complete Joint Penetration Weld**

<table>
<thead>
<tr>
<th>Base Metal</th>
<th>Filler Metal</th>
<th>Flux</th>
</tr>
</thead>
</table>

**Joint Design and Tolerances (Sketch) B-L1-S (see AWS D1.1 for details)***

Back gouge the back side to obtain complete joint penetration (CJP).

**Preparation of Base Metal**

**Electrical Characteristics**

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Welding Power</th>
<th>Flux</th>
<th>Base Metal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Size</td>
<td>Amps</td>
<td>WFS</td>
</tr>
<tr>
<td>Preheat</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cleaning
**Visual Inspection**
Using the AWS welding inspection tool kit, evaluate the entire length of the weld to determine if it meets the requirements set forth in AWS D1.1 Welding operator Qualification section.

<table>
<thead>
<tr>
<th></th>
<th>Acceptable</th>
<th>Not Acceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cracks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Craters are filled</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overlap</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weld Reinforcement (flush to 1/8” max)</td>
<td>Acceptable</td>
<td>Not Acceptable</td>
</tr>
<tr>
<td>Undercut (max 1/32”)</td>
<td>Acceptable</td>
<td>Not Acceptable</td>
</tr>
<tr>
<td>Weld merges smoothly with base material</td>
<td>Acceptable</td>
<td>Not Acceptable</td>
</tr>
</tbody>
</table>

**Repairs**

---

**Destructive Testing Documentation**

**TENSILE TEST**

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Width</th>
<th>Thickness</th>
<th>Area</th>
<th>Ultimate Tensile</th>
<th>Ultimate unit Stress, psi</th>
<th>Character of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**GUIDED BEND TEST**

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Type of Bend</th>
<th>Results</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**VISUAL INSPECTION**

- Appearance _______________________
- Undercut _________________________
- Piping Porosity ____________________
- Convexity ________________________
- Test Date _________________________

Witnessed By: ____________________________________________

Other Tests

---

All-weld-metal tension test

Tensile Strength psi ____________

%Elongation in 2 inches ______________

Bend Tests:
- #1 ______
- #2 ______
- #3 ______
- #4 ______

WLD 290 Matt Scott 6/6/2012
Welder’s Name: _______________  Welder # __________ __________

Test Conducted by __________________________________________

Test Number

Per

We, undersigned, certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of section 4 of ANSI/AWS D1.1 (________) Structural Welding Code – Steel

Signed _____________________________
By _________________________________
Title _______________________________
Date ________________________________
Final Grades - WLD 290

Name: _________________ Instructor: _______________ Date: ____________

Welding Projects = 40%

<table>
<thead>
<tr>
<th>Out of</th>
<th>Out of</th>
<th>Out of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A  
Total Project pts. ________ / Total pts. Possible _______ X 40 = _______ %

Written Work = 20%

<table>
<thead>
<tr>
<th>Out of</th>
<th>Out of</th>
<th>Out of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

B  
Total Project pts. ________ / Total pts. Possible _______ X 20 = _______ %

Safety = 15%  
Each day of attendance is worth 3 points earned. Any safety violation will result in 0 points for the day.

Safety
<table>
<thead>
<tr>
<th>Out of</th>
<th>Out of</th>
<th>Out of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

C  
Total Project pts. ________ / Total pts. Possible _______ X 15 = _______ %

Employability Skills = 15%  
The following attributes will be assessed - attendance, attitude, time management, team work, interpersonal skills, etc.. Daily points (there are no excused absences, hence no points earned for days missed ) 3 pts = present and working for the entire shift; 2 pts = late; 1 pt = late and left early; 0 pts = no show.

<table>
<thead>
<tr>
<th>Out of</th>
<th>Out of</th>
<th>Out of</th>
<th>Out of</th>
<th>Out of</th>
<th>Out of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

D  
Total pts. earned ________ / Total pts. Possible _______ X 15 = _______ %

Final Exam 10%

<table>
<thead>
<tr>
<th>Written Exam</th>
<th>Out of</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practical Exam</td>
<td>Out of</td>
</tr>
</tbody>
</table>

E  
Total Project pts. ________ / Total pts. Possible _______ X 10 = _______ %

Add Lines A + B + C + D + E. This will give you your Final Grade

TOTAL % __________

FINAL GRADE __________
APPENDIX I

WELDING PROCEDURE QUALIFICATION TEST RECORD

PROCEDURE SPECIFICATION

Material specification
Welding process
Manual or machine
Position of welding
Filler metal specification
Filler metal classification
Weld metal grade*
Shielding gas
Flow rate
Single or multiple pass
Single or multiple arc
Welding current
Welding progression
Preheat temperature
Postheat treatment
Welder's name

*Applicable when filler metal has no AWS classification.

GROOVE WELD TEST RESULTS

Tensile strength, psi

1
2

Guided-bend tests (2 root-, 2 face-, or 4 side-bend)
Root
Face

1
2

Radiographic-ultrasonic examination
RT report no
UT report no

FILLET WELD TEST RESULTS

Minimum size multiple pass
Maximum size single pass
Macroetch
Macroetch

1
2

All-weld-metal tension test
Tensile strength, psi
Yield point/strength, psi
Elongation in 2 in., %
Laboratory test no

WELDING PROCEDURE

<table>
<thead>
<tr>
<th>Pass no.</th>
<th>Electrode size</th>
<th>Welding current</th>
<th>Speed of travel</th>
<th>Joint detail</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Amperes</td>
<td>Volts</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>R</td>
<td>G</td>
<td>L</td>
<td>A</td>
</tr>
</tbody>
</table>

We, the undersigned, certify that the statements in this record are correct.

Procedure no.
Revision no.