1

Welding Metallurgy

Objective

Learner will be able to:

- Explain the mechanical properties of metal.
- List the five different strength measurements.
- Analyze and interpret phase diagrams.
- Discuss the heat treatments used in welding.
- Identify how grain size affects metal's strength.

Orienting Questions

- ✓ What in metallic materials makes them different?
- ✓ What differences do we see in the characteristics of materials?
- ✓ What effects does welding have on materials?
- ✓ How do we control changes to materials when welding?

Keys for success

- ☐ Read and review required text along with this module
- ☐ Review key terms
- ☐ Do each and every activity in the module

Helpful Tips

- ✓ You can select the **BLUE TERMS** to learn more.
- ✓ If needed, there are **CLOSED CAPTION** buttons CC on the YouTube videos that will enable you to read along while you watch. The Closed Caption buttons are located bottom right of the video screen.
- ✓ Anytime you see **EXPLORE** click on link or image to learn about the subject.
- ✓ Anytime you see me, click me and let me read the text to you!

INTRODUCTION

METALLURGY, by definition, is the science of metals. Metallurgy is a very in-depth subject. There are full bachelor's degrees in metallurgy, so as you can imagine we will only be briefly touching the subject. Our focus is from the perspective of a welder and what welders must know in their daily work for the good of their product.

1.1 MECHANICAL PROPERTIES OF METAL

There are many different base metals and **ALLOYS**, and many are being developed for specialty applications all of the time. Each and every metal or alloy has different characteristics. These characteristics define what it is capable of and therefore what is suited for in application. We, as welders, must understand the material we are working with for safety reasons and quality of product. Proper use of welding materials is a must to ensure that the weld can withstand the application and not fail in its task. As a welder, we must determine the best way to approach a job. For example, we must take into consideration things like what type of materials are needed, thickness, work conditions, equipment available, welding position, distortion, and many other factors that may affect our quality of work and end product. Knowing and understanding the material is the first step in developing an approach for the work at hand. With each of these properties there is a varying degree of each characteristic depending on the elements in the alloy and you will see an overlap between the characteristics, such as the harder a material the more brittle it can be. You will find these term in chapter 25 of our text book "Welding Principles and Applications" (7th edition by Larry Jeffus).

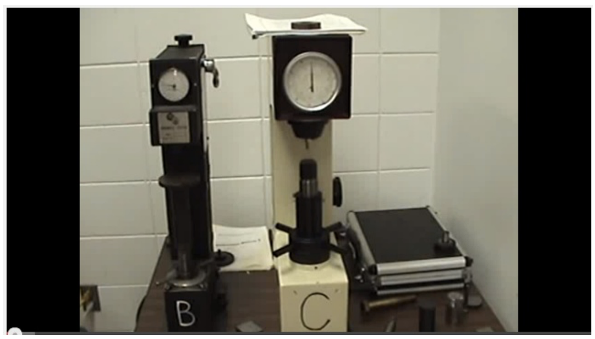
1.1.1 HARDNESS

HARDNESS (see Video 1) is defined as the resistance to penetration. The easiest way I know of to understand hardness is to think of drilling a hole. It is obviously easy to drill a hole in yellow pine wood, but what about oak wood, or metal. Think of the drill bit itself that is being used to create the hole. The drill bit is made of a hard material. Hardness is a characteristic that can be manipulated through heat treatment and working of the raw material. We'll discuss heat treatment in much greater detail in later sections. Meanwhile, explore information about Hardness and Hardness Testing tools (see).

EXPLORE: Another way to explain Hardness

Watch the following videos by clicking on the images.

Video 1: What is Hardness?
(Standard Youtube License)



Video 2. Rockwell Hardness Testers Video
(Standard Youtube License)

1.1.2 BRITTLENESS

BRITTLENESS (See Explore) is defined as the ease at which a metal will crack or break apart without noticeable deformation. A good example of a brittle material is glass. Glass when it breaks fractures and does not deform. So when you were a kid at home playing ball in the house and broke mom's vase, as punishment, you might have had to glue it back together. Gluing pieces of the broken glasses together was possible due to the brittleness of the material and the lack of deformity as it fractured. The vase became a puzzle with many little pieces.

EXPLORE: Schematics of typical tensile test fractures – Brittleness

1.1.3 DUCTILITY

DUCTILITY (see Explore) is defined as the ability of a material to be changed in shape by being twisted, drawn out, and bent without cracking or breaking. We find with welding and fabrication ductility to be an important characteristic with the structures we build and the welding wires we use to weld structures. The wire as it is produced must be ductile as it starts as a larger diameter round wire and is drawn (stretched) and reduced in diameter until it reaches the desired diameter. If the raw material was not ductile we would not be able to draw it down to a working size.

EXPLORE: Schematics of typical tensile test fractures

1.1.4 TOUGHNESS

TOUGHNESS (see Explore) is defined as a metals ability to withstand forces such as impacts or sudden shock without fracturing and or breaking. Figures 1 illustrates toughness from a Stress and Strain point of view. When thinking of toughness I think of a bulldozer bucket. It must be a tough material as it pushes dirt and debris. The constant abrasion and shock it under goes. If the materials were not tough the owners would be replacing the buckets or repairing them weekly if not daily taking operation of this heavy equipment out of the realm of being economical or feasible.

Explore: Another way to Explain Toughness

Click the following images to learn about the subject

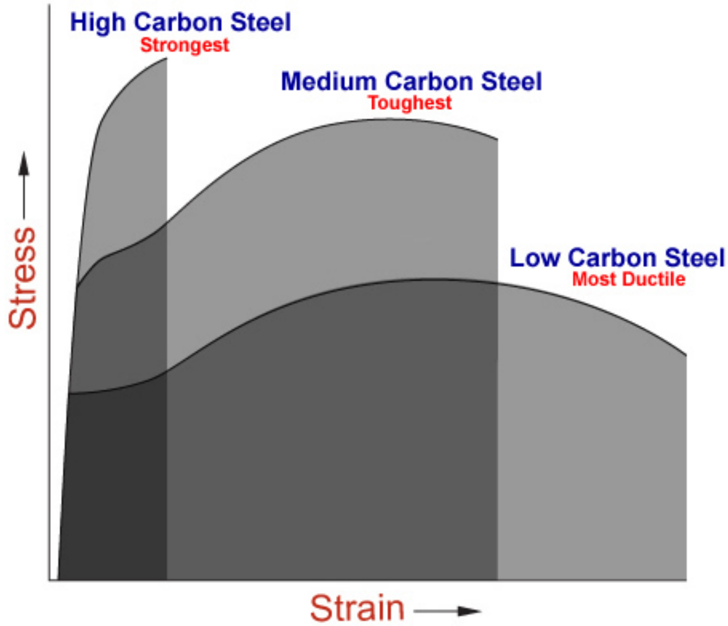


Figure 1: Illustration of metal materials and durability (NDT Resource Center, 2014)

1.1.5 STRENGTH

STRENGTH is a characteristic that has many different types of forces that are a measurement of its ability to resist deformation. The forces can be pulling, crushing, slicing, and or twisting. With so many different forces capable of being applied we must be able to define / measure a material's ability to resist each one. The terms noted and defined below are measurements of these different forces. For design reasons we must fully be able know the limitations of each to make sure the material for an application will live up to its purpose and design or else the consequences can be dire and even lead to death if the wrong material is selected. Even though material selection is a responsibility of the design engineer, as welders we must understand the material in order to control what the heat of welding might do to the base material (see Explore).

The heat of welding can change its characteristics such as a making a hard material soft or a soft material hard and therefore affecting its strength.

EXPLORE: Influence of Temperature to Metal Strength

1.1.5.1 TENSILE (YIELD STRENGHT, YIELD POINT, ULTIMATE TENSILE

As welders, **TENSILE** is a term most of us have heard or used on more than one occasion. The strength of most welding electrodes for steel are identified with a measurement of its tensile strength. Tensile is a materials resistance to pulling forces. We see tensile many times used when identifying electrodes.

With most welding electrodes we see the tensile measurement identified in thousands of pounds per square inch or you'll see it as KSI. Stick welding with a 6010 electrode this tells us that it has 60,000 pounds per square inch of tensile strength. 60,000 pounds of tensile strength tells us he can withstand 60,000 pounds a pulling force. This doesn't mean that a single electrode in raw form will withstand this might force. However, It does mean that one solid inch of welded material can withstand 60,000 pounds of pulling force.

Tensile is a very important property and there are many additional factors that we need to consider. Engineers should not work off of the tensile as a final value when designing a structure. When discussing tensile - we are talking about how much force withstand until it fails and separates or breaks. If tensile is all the engineer uses to calculate measurements of strength, he would see a lot more failures of structures. Many times, what is more important to a design engineer will be yield strength. In other words, what you should know is that even though many times we reference Tensile strength, in design, the more important data will be the yield strength. Design to the point the materials will change under load prior to complete failure to ensure his design works under the yield strength to ensure the structure isn't over or pushing the failure point. Yield strength is a measurement of how much force of material can withstand before it permanently changes in shape. Mostly, all materials have what's known as elasticity. **ELASTICITY** is materials ability to spring back from a certain amount of force much like the waistband in your underwear. But there are limitations to how far material can stretch before can it will no longer rebound. This is just like the waistband your underwear it can only stretch so far before it will no longer stretch back. Materials are the same way. Yield strength is that measurement, it measures how for the material can stretch and still rebound or stretch back. Beyond this point the material begins to change shaper what's known as necking down as it reduces in size by cross-sectional area or to say that the diameter is reduced to become smaller therefore with smaller size we see a reduction in strength and quicker to fail. When talking about yield strength we also see yield point. **YIELD POINT** is the point at which the material no longer will rebound or it loses its elasticity. Many times we also hear the term ultimate strength…**ULTIMATE STRENGTH** is what we really can talk about when we talk about tensile. Ultimate strength is the measurement of how much force it takes to take the material to complete failure, the ultimate amount of force it can withstand. As you can see the design engineer will be more worried about these other measurements such as yield strength and yield point more than just the ultimate tensile in design. He needs to know how much force can withstand before it loses that elasticity and begins to change affecting its strength (see Figure 2). This strength measurement will be much more critical for that design rather than the ultimate tensile and knowing how much it can withstand before failure.

EXPLORE: Click here or image below and explore

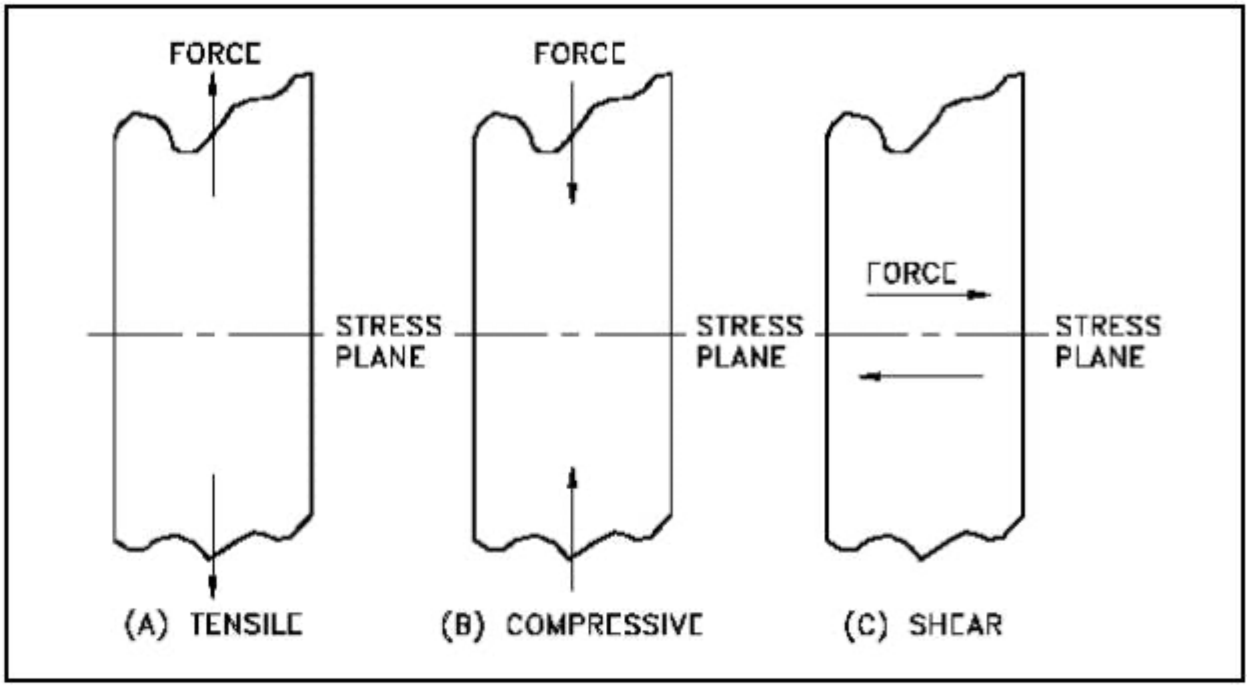


Figure 2: Types of Applied Stress (EngineeringBlog.com, 2011)

1.1.5.2 COMPRESSIVE

COMPRESSIVE strength is a measurement of the materials ability to withstand crushing forces. When thinking of compressive strength he can be a critical characteristic when designing of structures. Think of a high-rise in New York City. Think about all the floors high that building may go. Now think of the multiplied force for each floor it goes higher. The design engineer has to do it a lot of thought and calculations for that multiplied force for floor of after floor after floor and tons and tons and tons of overall compressive force being applied to the base structure the foundation. Have you seen the documentaries on the television show in the rebuilding of the twin towers in New York City? If you have, you seen the size of the foundation and how deep into the ground they've had to dig and how large the beams that support all of that weight. It seems almost common sense with a large structure for the amount of compressive force, for what about a just normal one-floor building? Even a one-story building is a tremendous amount of force on the main structure. Think about a normal industrial / commercial building, the roof structure itself, the air-conditioning units or heaters, and then again the time of year where we may see frozen precipitation such as snow and ice on that rooftop. The designers have to take all of that into consideration to make sure it can withstand the amount of force and weight that can be applied (see Figure 3). One small miscalculation and we see collapse structures.

EXPLORE: Click here or image below and explore

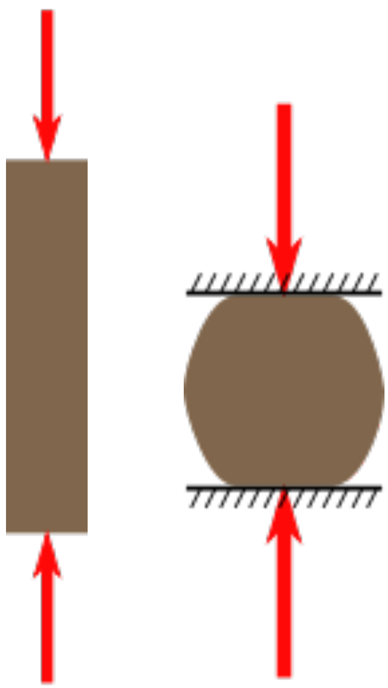


Figure 3: Compressive and Barreling (Wikipedia, CC BY-SA 3.0)

1.1.5.3 SHEAR

SHEAR STRENGTH is the ability of materials to withstand slicing forces trying to cut it apart. Many times in fabrication will use a metal Shear. A metal Shear is nothing more than a very large high-power set of what we have known for years is handheld scissors or shears. Even though it may use a much longer larger blade and hydraulic force it can cut through thick materials, steels and stainless steels. But how does that apply to force and/or design of structures? When designing structures many parts will withstand shearing force. Some connections may be mechanical connections using bolts or rivets. Bolts or rivets are rated by their ability to withstand shearing force. When a main beam is going into a girder, the share of the hardware is critical. If the hardware cannot withstand this amount of force we conceive this bolted connection completely separate. This is considered Shear force because the main beam is static it is a fixed structure not moving. But the girder floor joist or bar joist as it meets that main beam will be under a tremendous amount of load. These structure pieces support the roof for the floor and all the force of everything applied onto that. Where these to meet if it is not a solid connection we can see failure and because of these two pieces going in different directions (see Explore) it creates a Shear just like a pair of handheld shears the two blades going in opposite directions. Another time we think of Shear is off-roading. With many operating vehicles the suspension components are under a tremendous amount of force is the vehicles go up and over objects in the components twist and turn going in different directions. If the hardware cannot handle the shearing force, the suspension components will fail. Many times with hardware you'll hear the term, especially with off-roading, *hardware a grade 8 bolt*.

EXPLORE: Types of Stress

1.1.5.4 TORSIONAL

TORSIONAL strength is the ability of materials to withstand twisting forces. When thinking of twisting forces I think of vehicle components such as drive shafts axles and all of these different components that are going through twisting motion and force. The wrong selection of material and we would see a lot more failures.

EXPLORE: Another way to explain Torsion

1.2 Heat Treatment Techniques

Heat treatment is a technique used with metallic materials to control different strengths. Heat treatment is an exact science. It took a lot of time and effort from engineers and metallurgist to have gone into developing tables and charts - notice phase diagrams which detail what happens to materials at different temperatures and how it cools. By controlling the temperature it reaches, the cooling rate is able to control the physical characteristics of that material and/or manipulated. We can take a soft material and make it hard; we can take a hard material and make it soft. With heat treatment this is done intentionally but as welders, due to the fact that we introduce a tremendous amount of heat when we weld we must be mindful of how much heat we do introduce. Also, how it cools so that we don't change those physical characteristics beyond what is acceptable. On very critical materials it is not unheard of to send it off to be heat treated after welding. This is known as post weld heat treatment. Post weld heat treatment is done to ensure that the strength in characteristics are maintained even after welding because many times, doing everything right and paying very close attention to what we do…we can still alter those physical characteristics. Heat treatment is very expensive and requires the material to be put into a large oven and reach a specific temperature. It will then be held in the oven for a specific amount of time to ensure the heat fully penetrates through the part and reaches the desired temperature. Then depending on what characteristic we need the way it is cooled will aid in gaining proper characteristics. The next terms you will hear our techniques in which we control this cooling rate.

EXPLORE: Another way to explain Heat Treatment in Metallurgy

1.2.1 QUENCHING

QUENCHING is a term that defines how the material is cool and there are several different methods. Each of these methods has different cooling rates. First we have a molten salt bath. The molten salt bath is the slowest of the quenching methods. The slower material cools the softer we can maintain it. In its basic form a molten salt bath is taking a metal part and basically covering it in raw salt. By doing this it helps it to hold the heat therefore controlling the cooling rate. Next, there is air quenching. Air quenching is nothing more than air moving across the part. Whether it's the draft in a room or a fan directly moving the air, the air movement will help to pull him away from the part therefore cooling. Oil quenching is just what it sounds like, submerging the parts in a vat of oil. Done properly oil quenching will produce desirable characteristics but can be hazardous if done in properly. The part wants immersion oil must be allowed to fully cool within that oil not just dipped and pulled out quickly. If only dipped and pulled out quickly we run the risk of hitting the flashpoint of the oil in catching the oil on fire. Next, water quenching we use it a lot as welders in training and practice. It's very inexpensive and safety use, and does an adequate job in quickly cooling the material so that we can continue to practice our welding techniques. This is okay and practice, but not for real-world parts. Water quenching as a quickly cools the material cause of material to harden. The harder the material the more brittle or cracks sensitive and typically is not good for a metallic component. The fastest cooling technique or quenching method is Brine quenching. Brine is saltwater. The main difference is how the water comes in contact with the part when submerged. In just plain water when we submerge a hot piece of material we find water will boil around that material giving off oxygen bubbles, so the water does not remain in constant contact with the part. Brine the saltwater keeps the water in contact with the parting keeps it from boil. Brine keeping the water in contact with the part therefore cause the part to cool much faster.

1.2.2 ANNEALING

ANNEALING (see Figure 4) is the process of taking metal material to its soft point. As a heat treatment technique it is heated in an oven to a specific temperature, held there for a specific amount of time, but the important part is how it's cool. It is cooled in the oven or furnace at the lowest possible rate to control the grain structure. In other words, the smaller the grains the softer the metal material and the softer the metal material the more the metal become ductile. This whole process is called the annealing process.

As we talked earlier about our welding wires being drawn into shape, the making of that welding wire is a long process. Welding wires stretches and becomes hard when it is cold worked. There is a point at which the metal material is too hard to continue to be drawn. At this state, it must undergo heat treatment to fully anneal the material. Once annealed or taking metal to its soft point we then continue the process of drawing the welding wire down to size. This process will be repeated as many times as required in order to get it down to his proper size.

As you can imagine this can be an expensive process. The expense is fueling the oven/furnace and holding the item to be annealed in the oven/furnace for a designated amount of time and controlling the rate of cooling. Note, this is a slow as possible that may take hours to reach room temperature. Therefore we run the oven and furnace for an extended length at reduced temperature to begin metal cooling process. This entire process is economical when done at a large scale.

EXPLORE: Click here or image below and explore

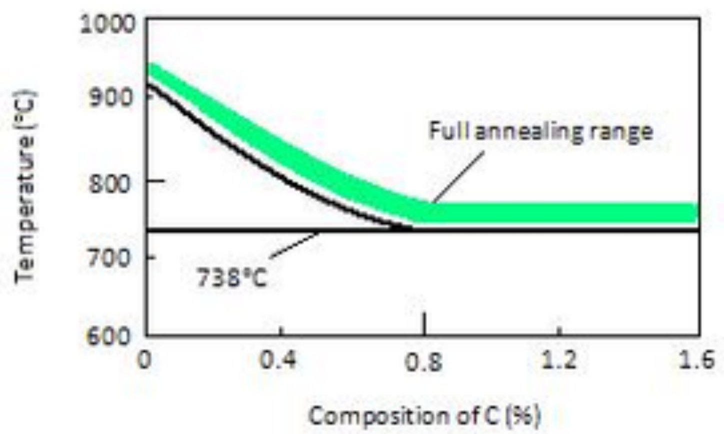


Figure 4: Image of full annealing temp range (image provided by George lade, 2008, Wikipedia)

1.2.3 NORMALIZING

Normalizing (see Figure 10) is a process that is very similar to annealing. It is a heat treatment process. We are not trying to take it to its fully soft state. We do want to continue to heat up in an oven/furnace to a designated temperature of 1700-1800 degrees Fahrenheit. Hold the metal in oven/furnace for the required amount of time…the amount of time depends on the thickness and size of the item and could range from 30 minutes to a couple of hours. Keep in mind that the main difference is how the metal cools. Normalizing allows metal materials to cool in open air until it reaches room temperature. By doing this we would get higher strength measurements than if we annealed the item (tensile), hardness and less ductile than annealing.

EXPLORE: Normalization

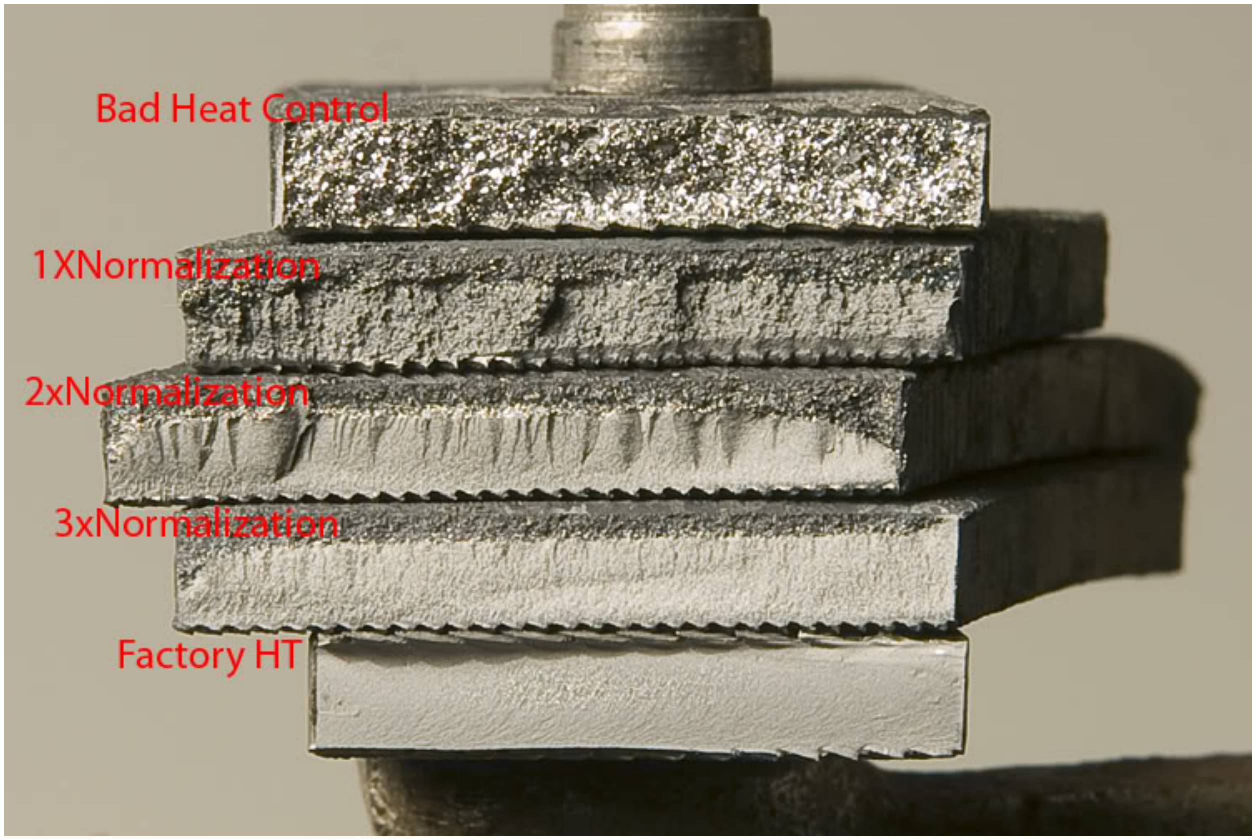


Figure 5: Normalization (image provided by Paleo tube, 2011)

1.2.4 TEMPERING

TEMPERING (see Figure 6) is the process of reheating the part that has been hardened through heating and quenching. Tempering is a big part of many operations and tools and products. By tempering a metal item, such as a pair of pliers, we are able to keep the strength and hardness along with controlling the amount of toughness that reduces brittleness. For example, common hand tools are tempered. This is very important to ensure that the metal materials or tools can have hardened jaws to perform tasks and not break. This is seen in common tools like pliers, hammers, and many other tools used daily. Without tempering the tools, we would find them too hard, cracked, or fall apart when being used.

So many times in welding class, students will wear out a chipping hammer. Wearing out chipping hammers is completely understandable but once we grind in trying to reshape the hammerhead…we lose the toughness and hardness. A reused and reshape hammerhead will no longer hold its strong point. To regain the temper it would not be economical to do so as we would have to put an end of an oven, heated to the required temperature, hold it at that temperature for the specified amount of time, and control the rated will at which it cools. After this process we would have to reheat the material to a lower temperature and again control the rated, which it cools. For a use tool, this would be way too expensive and exceed the value of that tool. But we can attempt to regain some of the characteristics manually. It won't be as good as a brand-new hammerhead but will be better than if we did not attempt to re-harden the metal materials. We can do this by heating the material with the torch after reshaping the head until we see it cherry red in color. Once we see the cherry red color we need to water quench the hammerhead, which hardens it as it cools it quickly. But this is not enough in itself; we must then slightly reheat the part just shy of being cherry red in color. Then we will want to let the hammerhead air cool to the touch. By doing this we remove some of the hardness but regain some toughness so that the hammerhead will hold up longer. As I said before, the process will not make a brand-new product but it can lengthen the life of the tool.

EXPLORE: **Click here or image below and explore**

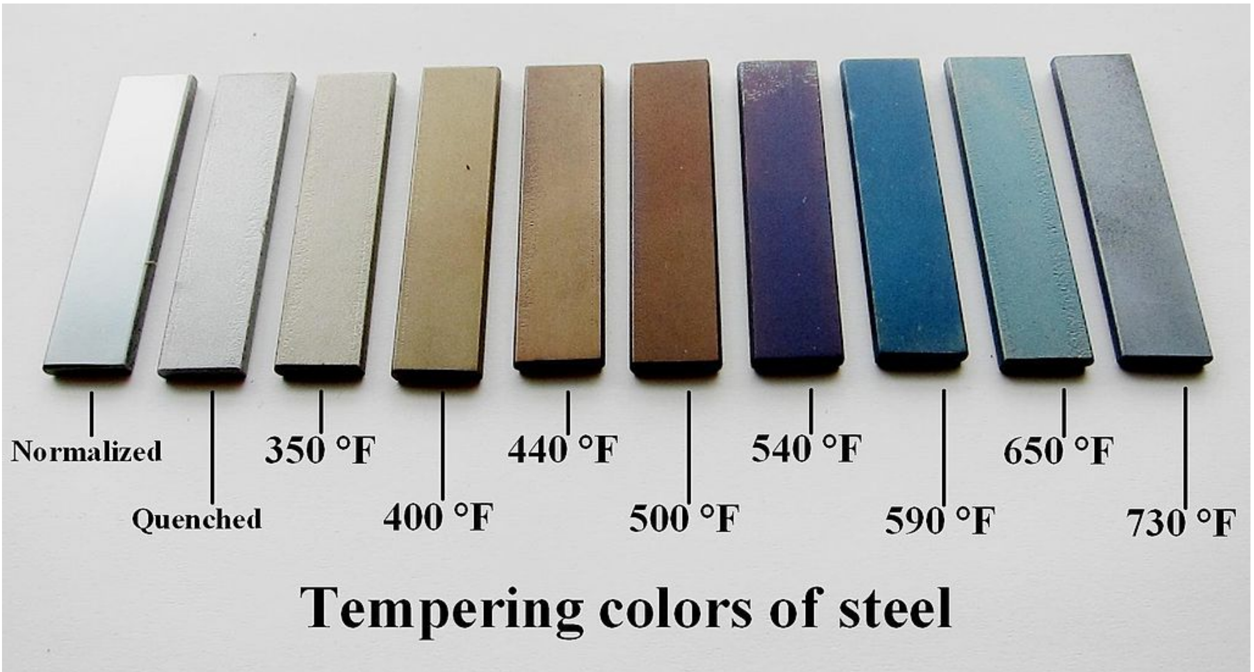


Figure 6: Tempering Standards (Image provided by Zaereth, Wikipedia, 2012)

1.3 HEAT CHART / PHASE DIAGRAM

As mentioned earlier in the heat treatment section, metallurgist engineers and other professionals over time have developed phase diagrams and heat charts. A phase diagram and heat chart details what happens to a material at different temperatures, some materials will soften and even lose their magnetic properties. This concept is hard to imagine when we think of most steels as we normally think of them as being magnetic. But at certain temperatures steels do lose their magnetic properties. So again, as welders, we must understand how the heat we introduce into the base metal effects that base metal and if we introduce too much heat what we might expect so that we can put corrective actions in place which may require post weld heat treatment to regain the proper characteristics. The area near weld in the base metal that is affected by the heat is known as HAZ or the Heat Affected Zone. The **HEAT AFFECTED ZONE** is where we typically will see the changing characteristics of the base metal and the internal structure.

The phase diagram and or heat chart (see Figure 7) gives us a full picture of what happens to the material at the different temperature ranges. With this knowledge we can understand the temperatures we must be cautious not to get near or cross, and if we do what it will do to the material. We can monitor the materials temperature through the welding process with a number of tools:

- Temp Sticks - most common and inexpensive
- Infrared Temperature guns
- Thermocouples

EXPLORE: **Click here or image below and explore**

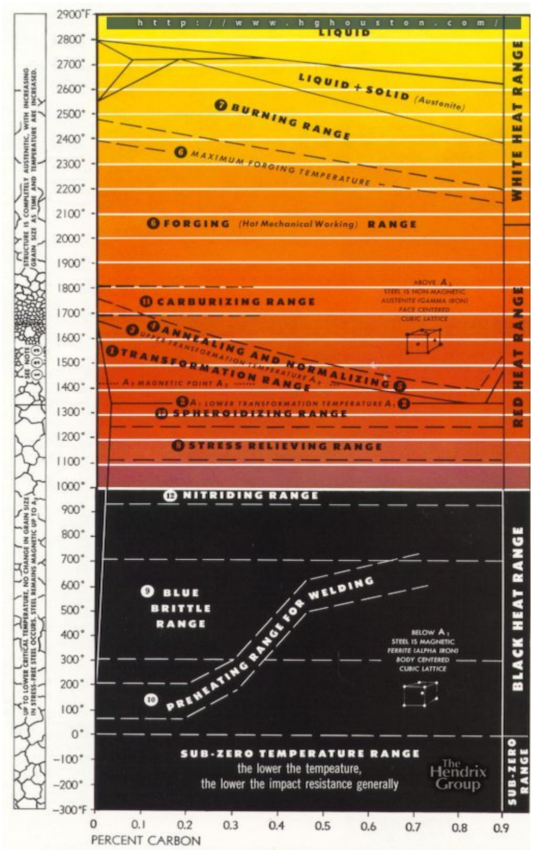
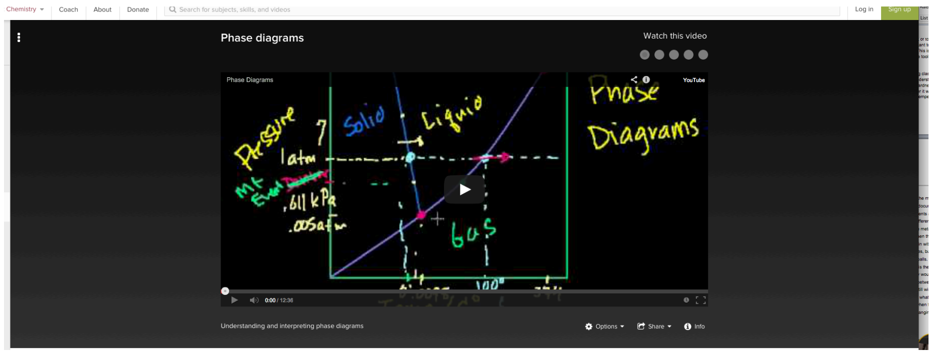


Figure 7: Heat Chart (Map provided by Tempil in The Hendrix Group, 2013)

1.3.2 PHASE CHANGE DIAGRAMS

In a phase diagram (see Video 3) you will see and hear different terms you may be unfamiliar with. Terms such as pearlite, cementite, austenite, martensitic, ferrite are all terms referring to the crystal structure and grain size of the crystals and from this we can understand the different characteristics or the materials ability to absorb alloying elements. As welders, our day-to-day duties normally don't have us using these terms. However, we must have a general understanding of what the terms mean in order to converse with Engineers on the jobsite.

Watch the following videos by clicking on the images.



Video 3: Understanding and interpreting phase diagrams (By Khan Academy ,2014)

1.3.3 MICROSCOPIC STRUCTURAL OF METAL

Have you ever seen a piece of metal under a **MICROSCOPE**? What kind of structure when magnified does a metallic piece of material have? The truth is, the structure of the material, is crystalline. It's hard to believe that a metal would resemble crystal when magnified (see Figure 8). Most of us would not imagine a metal to have a crystal form; the two structures don't seem to work together. I think of crystal is being very brittle almost like glass unlike what I expect out of a metal object. But the internal structure as it is crystalline in form, changes its structure at different temperatures and then again in the way that it cools. These changes alter the physical characteristics of that base metal. The smaller the crystal grain structure the softer it is considered, in the softer the more ductile. The larger the crystal grain structure the harder that material as the larger the grains the more surface area and contact the individual crystals have with one another. These phase diagrams document what we can find with different alloys. An alloy is a material that is a mixture of different elements and not pure in form. Most materials today are alloys and more are being developed every day for different applications by changing its chemistry in the percentages of the elements that comprise that base metal. With all of these new alloys new welding electrodes are being developed to work with them. When thinking of an alloy I think of an old science experiment when I was a kid. The science teacher walked in with a bucket full of baseballs and asked the question to the class is it full? Of course all the kids said yes, but the teacher then proceeded to take a bucket full of marbles and poured it into the bucket of baseballs. The marbles filled all the spaces in between the baseballs. The teacher then asked the question is the bucket that is now full of baseballs and marbles fall? Most times the students are catching on they would say no. And the teacher proceeds to fill it full now with sand. The sand again will fill the spaces in between the baseballs and the marbles. The teacher again asked the question, is it full. The students still wise to the trick answer no, and the teacher then fills the bucket full of water. This is a demonstration of what we find with our point of metals. The different elements in their purest form at the atomic level, when their mixed together the atoms of one element merge with the other filling gaps in its structure and changing its characteristics.

EXPLORE: Click here or image below and explore

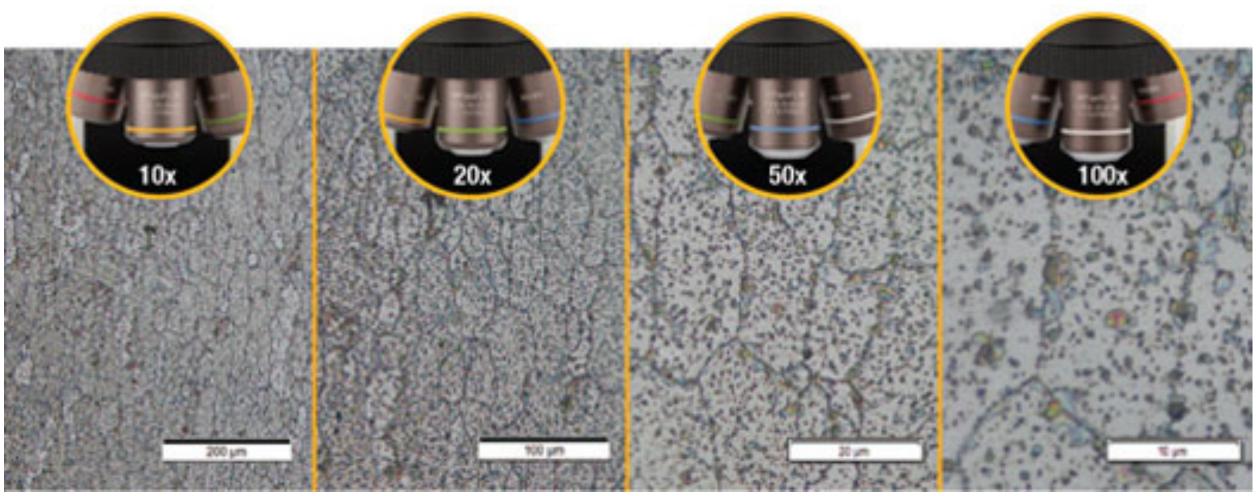


Figure 8: Metal seen through the lens of a microscope (image provided by Olympus Corporation, 2014)

1.3.3.1 CRYSTALLINE STRUCTURE OF METALS

There are a number of different types of crystal structures that we expect and know that are common with metal. As welders, we must understand crystal structure do lead to metal characteristics. The heat from welding can change metal structure, therefore, changing characteristics. Our goal, as welders, is to minimize the effect of welding like heat input into metal material to minimize change in characteristics. You may ask why do we even need to know this but the truth is we need to be able to converse intelligently with the design engineers and the metallurgist with new products or alloys that we are unfamiliar with to ensure the quality of product we are working on. In its basic sense we need to understand when we hear these terms what are we talking about, and the truth is when you hear body centered cubic unit cell (see Explore), face centered cubic unit cell (see Explore), or hexagon all close packed cubic unit cell are all different crystalline structures that we find in metal. Below you will see a list of different structures of crystals as seen in metals.

EXPLORE: Body Centered Cubic

EXPLORE: Ace Centered Cubic

MAJOR CONCEPTS

KEY CONCEPTS

- Physical characteristics
  - Brittleness
  - Ductility
  - Toughness
  - Hardness
  - Strength
    - Tensile
      - Yield Strength
      - Yield point
      - Ultimate Tensile
    - Compressive
    - Torsional
    - Shear
    -
- Structure of material
- Heat from welding can affect physical characteristics
- Why heat treatment is used

KEY TERMS

Alloy

Annealing

Brittleness

Compressive

Ductility

Elasticity

Metallurgy

Hardness

Heat Affected Zone (HAZ)

Heat Treatment

Normalizing

Phase Diagram

Quenching

Tempering

Tensile

Torsional

Toughness

Shear

Strength

Ultimate Strength

Yield Point

Yield Strength

Full Glossary

ASSESSMENTS

MODULE REINFORCEMENT

WLD 204 Physical Characteristics

Multiple Choice

Identify the choice that best completes the statement or answers the question.

____ 1. ____ is the ease with which a metal will crack or break apart without noticeable deformation.

a) Hardness
b) Toughness
c) Brittleness
d) Strength

____ 2. ____ may be defined as resistance to penetration.

a. Hardness
b. Brittleness
c. Toughness
d. Strength

____ 3. ____ is the property that allows a metal to withstand forces, sudden shock, or bends without fracturing.

a. Hardness
b. Brittleness
c. Toughness
d. Strength

____ 4. ____ strength is the property of a material to resist being crushed.

a. Tensile
b. Compressive
c. Shear
d. Torsional

____ 5. ____ strength is the property of a material to withstand a twisting force.

a. Tensile
b. Compressive
c. Shear
d. Torsional

____ 6.____ strength is a measure of how well a part can withstand forces acting to cut or slice it apart.

a. Tensile
b. Compressive
c. Shear
d. Torsional

____ 7.____ is defined as the maximum load, per unit of area, to which a material will respond with a deformation directly proportional to the load.

a. Elastic limit
b. Elasticity
c. Tensile strength
d. Yield limit

____ 8. The phases and temperatures at which an alloy exists is summarized in a (n) ____.

a. crystal diagram
b. WPS
c. phase diagram
d. phase graph

Completion

Complete each statement.

1. ______________________ is the ability of a metal to be permanently twisted, drawn out, bent, or changed in shape without cracking or breaking.

2. ______________________ is the process of reheating a part that has been hardened through heating and quenched.

WLD 204 Physical Characteristics

ANSWER KEYS

ANSWERS TO ASSESSMENT

MULTIPLE CHOICE (Answer Key)

1.	ANS: B	PTS: 1	REF: 643
2.	ANS: A	PTS: 1	REF: 643
3.	ANS: C	PTS: 1	REF: 643
4.	ANS: B	PTS: 1	REF: 644
5.	ANS: D	PTS: 1	REF: 644
6.	ANS: C	PTS: 1	REF: 644
7.	ANS: A	PTS: 1	REF: 645
8.	ANS: C	PTS: 1	REF: 646

COMPLETION (Answer Key)

1. ANS: Ductility

PTS: 1 REF: 643

2. ANS: Tempering

PTS: 1 REF: 653

DISCUSSIONS

QUESTION 1

With each of the physical properties discussed in this module, name each property in relation to where it is considered critical to the property, product or application. (Example: Compressive strength critical in high rise buildings)

With each of the characteristics listed below from this module, please discuss each property in relation to an application where that property is critical in consideration for the product or application and why. (Example: Compressive strength critical in high rise buildings)

- Brittleness
- Ductility
- Toughness
- Hardness
- Strength
- Tensile
- Compressive
- Torsional
- Shear

QUESTION 2

What is the purpose of heat treatment?

ATTRIBUTION TABLE

Author/s	Title	Source	License
Hardox Lundin	Video 1: What is Hardness?	*https://www.youtube.com/watch?v=6I2yMEVLclc&index=6&list=PLYMPld7E7shzIBKiLoifEQGrqE8l8PsZd*	Standard YouTube License
Grant Logsdon	Video 2 Rockwell Hardness Testers Video	http://youtu.be/439POmkcG-E	CC BY-SA 4.0
NDT Resource Center	Figure 1: Illustration of metal materials and durability	https://www.nde-ed.org/EducationResources/CommunityCollege/Materials/Mechanical/Toughness.htm	Fair Use Provision https://www.nde-ed.org/TermsConditions/termsconditions.htm
EngineeringBlog.com	Figure 2: Types of Applied Stress	http://engg-learning.blogspot.com/2011_03_06_archive.html	Engineering learning.blogspot Posted by Illusionist https://www.blogger.com/profile/04348893784203932481
Wikipedia.com	Figure 3: Compressive and Barreling	http://en.wikipedia.org/wiki/Compressive_strength	CC BY-SA 4.0
George Lade	Figure 4: Image of full annealing temp range	http://en.wikipedia.org/wiki/Annealing_(metallurgy)#Full_anneal	CC BY-SA 4.0

Eric Dobratz	Figure 5: Normalization	http://paleoplanet69529.yuku.com/topic/47099/Normalization-Grain-Size-Control-Experiment-----normalize#.U_ursEs1qD9	Section 4. License http://www.crowdgather.com/legal/
Zaereth	Figure 6: Tempering Standards	http://en.wikipedia.org/wiki/Tempering_(metallurgy)	CC BY-SA 4.0
David Hendrix	Figure 7: Heat Chart	http://hghouston.com/resources/material-property-data/pictorial-guide-to-basic-metallurgy.aspx	Used with permission
Khan Academy	Video 3: Understanding and interpreting phase diagrams	https://www.khanacademy.org/science/chemistry/states-of-matter/v/phase-diagrams	CC BY-SA 4.0
UNIVERSITY OF PENNSYLVANIA	SCHOOL OF ENGINEERING AND APPLIED SCIENCE (SEAS)	Figure 8: Face Centered Cubic	http://www.seas.upenn.edu/~chem101/sschem/ionicsolids.html	The Pennsylvania State University © 2014 Contact: http://www.psu.edu/copyright-information

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