MATERIALS™ EXPLORERS

BLADESMITHING

From ancient literature to modern movies, hand forged metal weapons have long captured the imagination. View some of the blades created for the TMS Bladesmithing Competition and design a blade of your own in this chapter that delves into the science behind bladesmithing.

In this module students will be able to:

- Compare and contrast alloys and pure metals
- Identify advantages and disadvantages of various metals when used in bladesmithing
- Calculate the ultimate tensile strength of various metals and alloys
- Apply knowledge of specific strength to discuss applications in other fields
- Distinguish between casting, hot forging, and cold forging

Class Activity

BLADESMITHING BATTLE

Background:
More than 75% of the elements on the periodic table are metals. Metals tend to be solid at room temperature, have high melting and boiling points, and high densities. Metals are also lustrous, malleable, ductile, and are good conductors of heat and electricity. When a metal is combined with another element, the resulting **alloy** often has more desirable properties than a pure metal. For example, pure iron is too soft to make a blade but adding carbon to it creates steel, a metal alloy which is strong enough to be sharpened. If chromium is also added, the alloy becomes resistant to corrosion. This is how stainless steel is made.

Bladesmithing, a practice that spans many cultures and millennia, is the art of making blades using equipment such as a forge, hammer, and anvil. Blacksmiths carefully select their materials, often metal alloys, based on the properties they will give the final blade. Most of the alloys used to make blades are forms of carbon steel. Carbon is necessary to make the metal hard, but too much carbon makes the blade less flexible and brittle, increasing the likelihood of breaking in battle. The chart below displays some common alloy additions to steel and the advantages and disadvantages of using each:

Metal	Advantages	Disadvantages
Chromium	Helps with hardening	Can cause steel to crack during forging
Tungsten	Makes a sharp, long-lasting edge	Difficult to forge
Manganese	Adds strength during heat-treatment	May be difficult to cast
Molbydenum	Helps steel remain hard at high temperatures	Very challenging to forge if present in high quantities
Nickel	Adds strength	Does not increase hardness

One way to quantify the performance of a blade is by calculating the **specific strength** of the material used to create it. Specific strength is a measure of a material's strength relative to its density. In other words, it is a measure of its strength to weight ratio—an important quality to consider when trying to create a strong but lightweight blade.

To calculate specific strength, a material's **ultimate tensile strength (UTS)** is divided by its density. Ultimate tensile strength refers to the maximum amount of **stress** a material can sustain before fracturing.

Class Activity

Problem

Dragons are attacking your kingdom and your homeland is not equipped with the right weapons to fight them. You realize that this is because local blacksmiths are not using the best metals or alloys to create their weapons. Using your extensive scientific knowledge, you set out to determine which materials would be best for forging new weapons. You decide to test the specific strengths of various metals and alloys to determine which material is best suited to create a dragon-slaying sword that is both strong and lightweight.

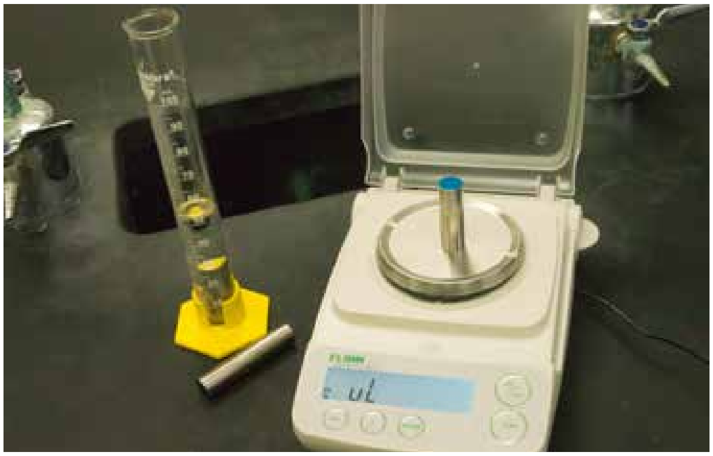
Task:
Your task is to determine the specific strengths of various metals and alloys and compose a letter addressed to the king, persuading him to use the material you think best suited to making a sword capable of slaying the dragons and protecting the kingdom.

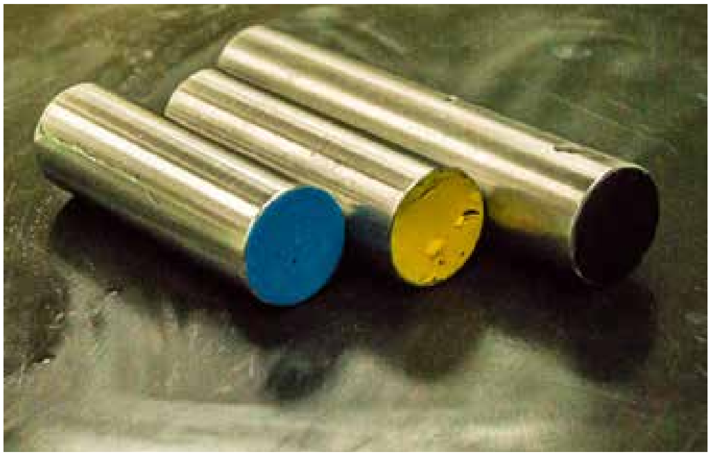
Requirements:

1. Your letter must use the results of your tests to justify which material you recommend.
2. Data should be collected in the table provided below.
3. The UTS for each sample will be provided by your teacher.
4. Calculate the specific strength of each sample using the following equation:

$$\textit{specific strength} = \frac{\textit{UTS}}{\textit{Density}}$$

Sample Name	Mass (g)	Volume (cm3)	Density (kg/m3)	Ultimate Tensile Strength	Specific Strength





Class Activity

Questions

1. **What is an alloy?**
2. **When making a blade, why would you use alloys instead of pure metals?**
3. **Compare the atomic arrangement in a pure metal to that of an alloy.**
4. **In what other fields would the specific strength of a material be taken into consideration and why?**
5. **While alloys often work best in bladesmithing, there are other applications where it is better to use a metal in its pure form. Identify one such application and explain why the pure form of the metal is preferable.**

Definitions

Alloy
A mixture of two or more metals, or a metal and other elements.

Specific Strength
A measure of a material's strength relative to its density. It is also known as the strength to weight ratio.

Ultimate Tensile Strength (UTS)
The maximum stress a material can withstand while being stretched or pulled before breaking.

Stress
A measurement of the force applied to the object per unit area. It can be calculated by dividing the force applied to the material by its cross-sectional area.

Extension Activity

WHAT DOES IT TAKE TO FORGE A BLADE?

Forging a blade is no simple task.

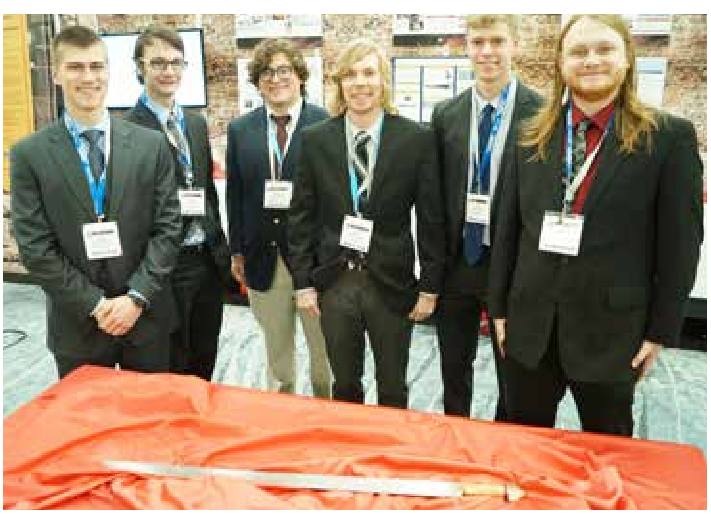
It takes creativity. The first step in creating any blade is to establish a vision and design. These designs are often only created after hours of research into traditional weapons and ancient cultures.

It takes dedication and endurance. With countless hours spent laboring over a hot forge, a blacksmith must hammer, grind, and test the blade until certain it meets his or her demands.

It also takes science. While movies are fond of showing red-hot swords being pulled from the forge and sparks flying as metal strikes metal, they rarely showcase the metallurgy behind the process. In order to create a powerful blade, blackmiths must first understand the properties of the metals and alloys available to determine which materials they should use. They need to understand a material's strengths and its limitations if they want an end product that is strong, durable, and useful.

University students from around the world learn this when they participate in the TMS Bladesmithing Competition. Every other year, teams are challenged to delve into the world of traditional metallurgy by using their theoretical knowledge to produce a real-life blade. Showcased here are just a few of the many incredible student pieces entered into the competition.

Norwegian Langseax
by Jackson Ade, Daniel Funk, Ryan Grant, Frederic Neiderer, Kevin Noto, Luke Shearer and Ryan Stevens of South Dakota School of Mines and Technology.
2017 TMS Wadsworth-Sherby Grand Prize recipients.



The winning team of the 2017 TMS Bladesmithing Competition set out to recreate history in the form of a 10th century Viking sword discovered in a Norwegian burial mound. The team also brought in some history of their own by including wrought iron taken from the site of a historic smelter on their university's campus. Adding this wrought iron to the layers of steel used in the sword's spine resulted in a more flexible blade that would be less prone to breaking.

The team also used a traditional Damascus steel design. Damascus steel is famed for being simultaneously harder and more flexible than other blades of its time and the distinctive ripple-like patterns that form on its blade make it iconic in the world of bladesmithing. Despite centuries of trying to recreate the traditional process for forging Damascus steel, it remains shrouded in mystery. This no doubt, is made even more difficult by the many legends that surround the process, such as quenching the blade in "dragon's blood."

Extension Activity

Bowie Knife
by Cody Fast, Casey Husk, Hunter Lottsfeldt, Lucas Teeter, Marco Teeter, Oregon State University.

A good forge is the heart of any foundry – so what happens if you don't have one? The team of students from Oregon State University can tell you. They didn't have access to a forge, so they made their own by repurposing a 20 pound propane tank and lining it with high temperature ceramic fiber insulation, refractory mortar, and bubble alumina.

Out of this forge, they created a billet of forge-welded Damascus steel which consisted of 24 alternating layers of two types of steel alloys. They then fashioned this billet into a blade modeled off the historical design of the Bowie knife.

Kukri
by Allison Loecke, Ryan Peck, Grant Bishop, Hunter Sceats, Kyle Heser, Connor Campbell, Colorado School of Mines.

The 2015 competition's third place recipients found their inspiration in South Asia. The kukri is the traditional knife of Nepal where it has been used for centuries by warriors and farmers alike who have relied on its front-heavy design for sharp, chopping blows. While most commonly used as an everyday tool for domestic and agricultural needs, the kukri is famous for its military use by the Nepalese army and Gurkha troops around the world.

Because the kukri design can vary widely in curvature, length, and construction across the various regions of Nepal, the team from Colorado School of Mines chose to add their own unique design and style variations to the recreated knife. They worked with local craftsmen to ensure the authenticity of their replica by matching their forging processes and materials to those used by Nepalese knife makers today.

Damascas Steel Khanjar
by Remigiusz Błoniarz, Estera Macho, AGH University of Science and Technology, Poland.

Imitation isn't just the sincerest form of flattery—it's a great way to learn. The team from AGH University of Science went to the National Museum in Cracow, Poland to study an 18th/19th century oriental Damascus steel blade in an attempt to recreate it using traditional blacksmithing techniques. Unlike pattern-welded Damascus steel where layers are forged welded together and folded, wootz is formed

Extension Activity

from re-melted steel in clay crucibles. The team created their own wootz ingot which was then formed into the blade through 85 cycles of forging and heating. The hard work ultimately paid off as the team's testing revealed that the microstructure of their blade matched their museum wootz blade sample.

Berkelium
by R. Connick, H. Vo, D. Frazer, W. Connick, R. Traylor, N. Bailey, J. Bickel, J. Austin, P. Hosemann, University of California, Berkeley.

The 2015 team from University of California, Berkeley won special recognition for their historical reproduction of authentic Saxon sword manufacturing techniques. Just as the Saxons would have originally searched for iron ore deposits, the team of students began by collecting magnetite, an iron ore, from a local California beach at low tide. The collected sand was spread thinly over a large area and magnets were carefully passed over the sand to extract the magnetite. The team then smelted the extracted ore to produce the steel that would become their blade.

Reproduction of the T19391 Sword from the Late Norwegian Iron Age
by David Brennhaugen, Espen Undheim, Raghed Saadieh, Rune Hagberg Stana, and Vincent Canaguier of Norwegian University of Science and Technology.

The Norwegian University of Science and Technology (NTNU) University Museum is home to the T19391 blade—a late Norwegian Iron Age sword originally discovered in the same county as NTNU. The sword is a prime example of the blades produced during a conflict-heavy period of Norwegian history and it shows the need for mass production in its simple design and lack of ornamentation. The team from NTNU set out to recreate the blade by first studying and measuring the original before selecting a high carbon steel which was flattened into a bar and then manually hammered into the shape of the T19391 blade.

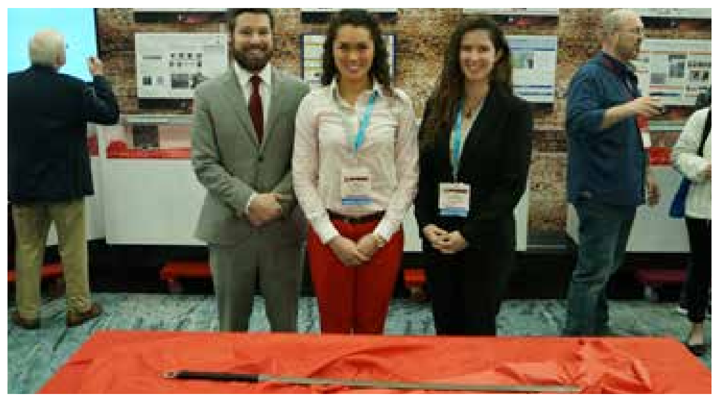
Dragonslayer: A Modern Myth
by Jacob Hullings, Emily Feng, and Emma McDonnell of Northwestern University, and Ric Furrer of Door County Forgeworks.

The team from Northwestern University found their inspiration in the Old English poem, *Beowulf*. Despite a life of legendary victories, the tale's eponymous hero is mortally wounded during a fight against a dragon when his seax, a single-edged knife, shatters on the dragon's hide leaving him open to attack. The bladesmithing team set out to recreate a historically accurate seax with one notable exception— their blade would be forged using ultrahigh performance steels, Ferrium® C61™ and C64®, to ensure that it was strong enough to avoid the critical failure of Beowulf's weapon.

A Rapier Eclectic
by Dylan Fitz-Gerald, Kyle Rosenow, Cam Atwood, Josh Ledgerwood, and Justin Boothe of California Polytechnic State University, San Luis Obispo.

Eclectic is certainly an apt description for the blade produced by the team from California Polytechnic State University. They set out to experiment with a wide variety of bladesmithing techniques in order to improve their own skills. As a result, each component of the blade presented new challenges ranging from fabricating custom tools for forming the bevels, to Computer Numerical Control (CNC) plasma cutting the ivy leaf pattern, to using a CNC lathe for forming the sword's pommel. The team's rapier is a testament to the many skills utilized in producing a quality blade and, of course, to the talent of the students who produced it.

Meteoritic Iron Han Dynasty Dao
by Emily Bautista, Cameron Crowell, Dale Morse, Andrew Pfaff, and Olivia Wilson of Virginia Polytechnic Institute and State University.



All the teams who enter the TMS Bladesmithing Competition "shoot for the stars" when designing and forging their blades, but one team took that mantra more literally than the others. They decided to use meteorite as the basis for their sword, a technique which goes back to 7000 BC in the Chinese sword making tradition. After sourcing an 8 pound meteorite, the team had to cast it into blanks which were then used to forge a traditional Han dynasty (206 BC – 220 AD) Dao, one of the four traditional Chinese weapons. Using the meteorite introduced nickel, phosphorous, and cobalt into the blade, each of which would ultimately influence the sword's characteristics.

Extension Activity

Questions

1. **What is the difference between casting and forging?**

2. **What are the advantages of forging?**

3. **During the forging process recrystallization occurs. What is recrystallization and why is this process vital to forging?**

4. **Describe the difference between hot forging and cold forging.**

5. **Many of the teams above designed swords based on historical weapons but a bladesmith can make anything from kitchen knives to throwing stars to a battle axe. What type of blade would you make? Create a poster that includes:**
   i. **an example of a blade that fascinates you, the history behind the blade and a discussion of the materials and processes used to make it.**
   ii. **a design or drawing for your own blade, inspired by your example.**
   iii. **a plan for producing your own blade which notes any changes to the materials or process you would recommend.**

MATERIALS™
EXPLORERS

Materials Explorers™ is a STEM educational outreach initiative of The Minerals, Metals & Materials Society (TMS). TMS is non-profit, international professional society with a mission to promote the global science and engineering professions concerned with minerals, metals, and materials.

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