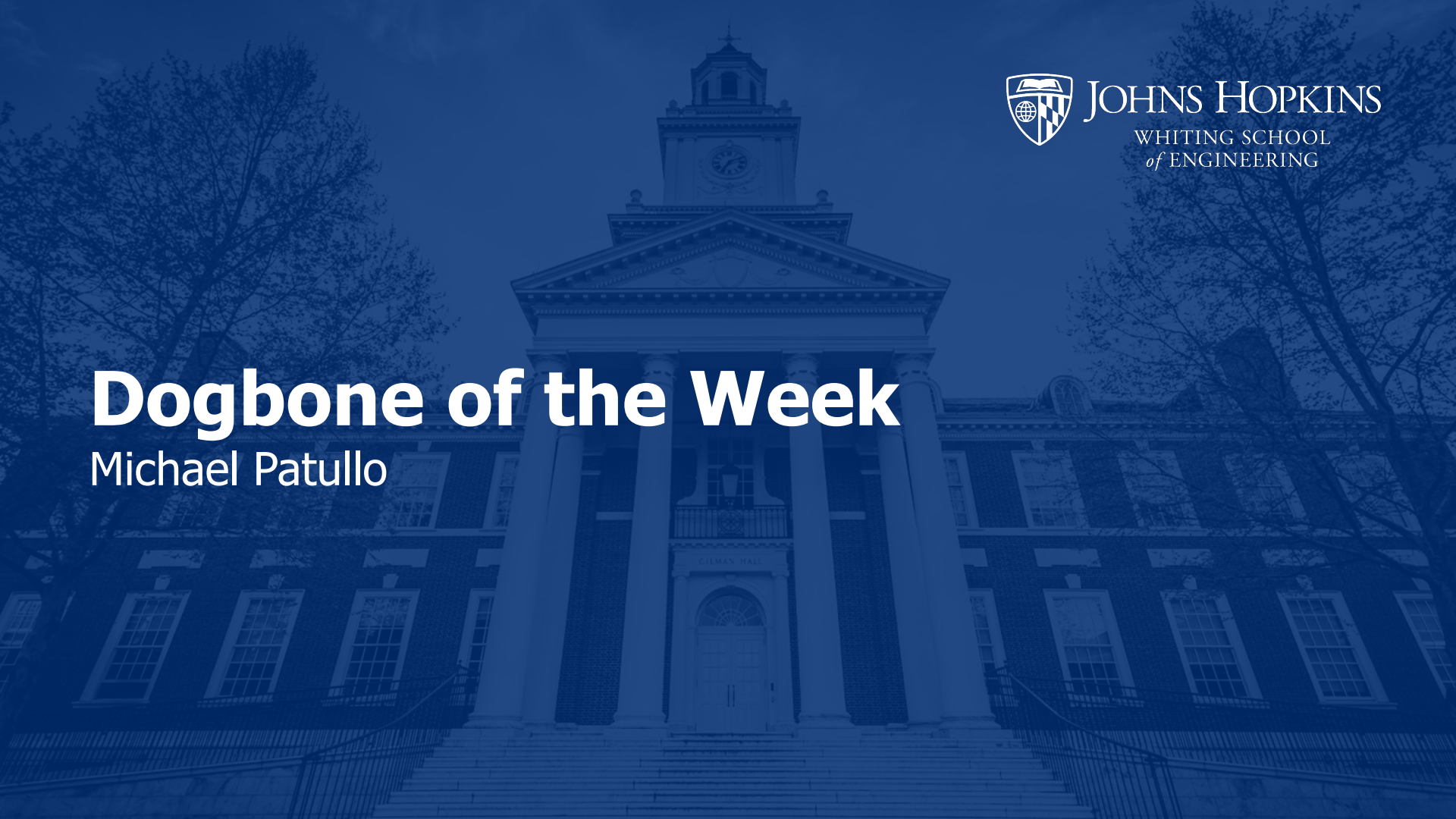


Dogbone of the Week

Michael Patullo

Sword Lore

- About once every 8-12 months I crave swords
  - idk why
- I went on a noble quest to find the most extreme sword
- My search concluded with one question:

What is tamahagane and why is it so important?

A Brief History

- **3000BC:** The first swords were made from molds of arsenical copper
- **1700BC:** Bronze swords appear in bulk near the Mediterranean
- **800BC:** Swords are finally made of iron and steel, as they are today

- Started as symbols of status, later used in war, and now almost exclusively ceremonial

A Brief History

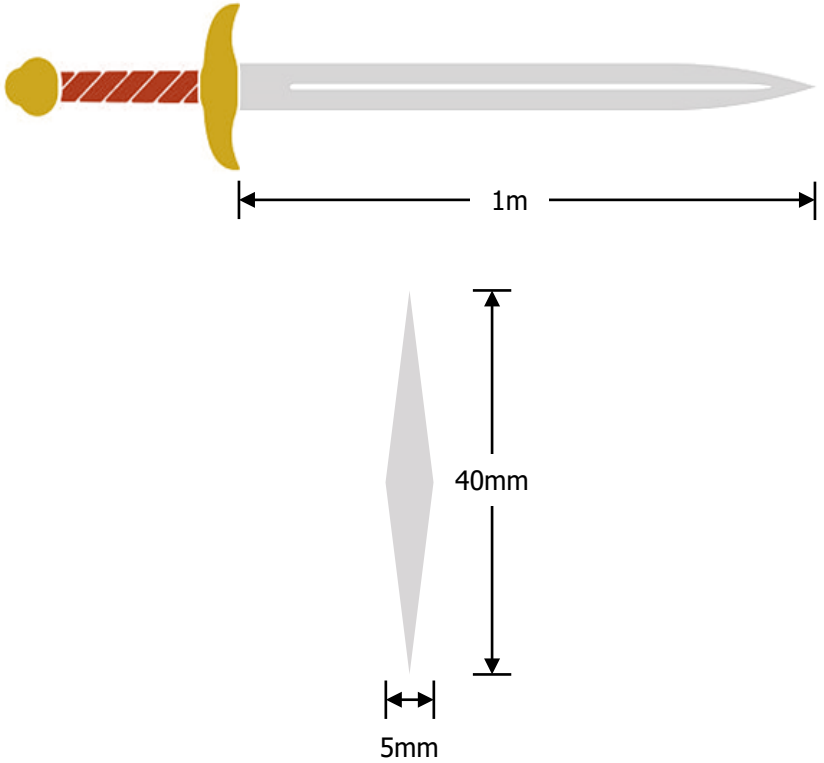
- Unique pommels, grips, guards, patterns, and geometries
- Every sword was crafted with the end user in mind

Clockwise from top left:

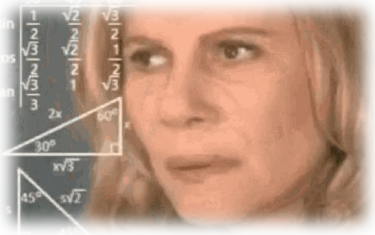
- Lorestan hand guard from 1000BC
- Celtic hilts inspired by Daniel
- Shamshir (Iran), Longsword (Croatia), Katana (Japan)
- Pattern welded blades made from optically dissimilar metals

Material Selection: The Design

- Hardness and stiffness are both important. For simplicity, let's only focus on stiffness right now
- 1m long, 40mm wide, 5mm thick with a mass less than 1.5kg
- The blade should deflect minimally ($\leq$1mm) under its own weight
- Must be hard but not brittle
- Can be forged and sharpened to a point; easily repaired
- Relatively inexpensive



Material Selection: The Index



- Mass: $m = AL\rho$
- Area: $A = \frac{bh}{2}$
- Moment of Inertia: $I = \frac{bh^3}{48}$
- Distributed Load Deflection: $\delta = \frac{FL^3}{8EI}$

$$\delta = \frac{FL^3}{8EI}$$

$$\delta = \frac{6FL^3}{Ebh^3} \qquad I = \frac{bh^3}{48}$$

$$\delta = \frac{6AL^4\rho g}{Ebh^3} \qquad F = AL\rho g$$

$$\delta = \frac{3L^4\rho g}{Eh^2} \qquad A = \frac{bh}{2}$$

$$\delta = \frac{3L^4 g}{h^2} * \frac{\rho}{E}$$

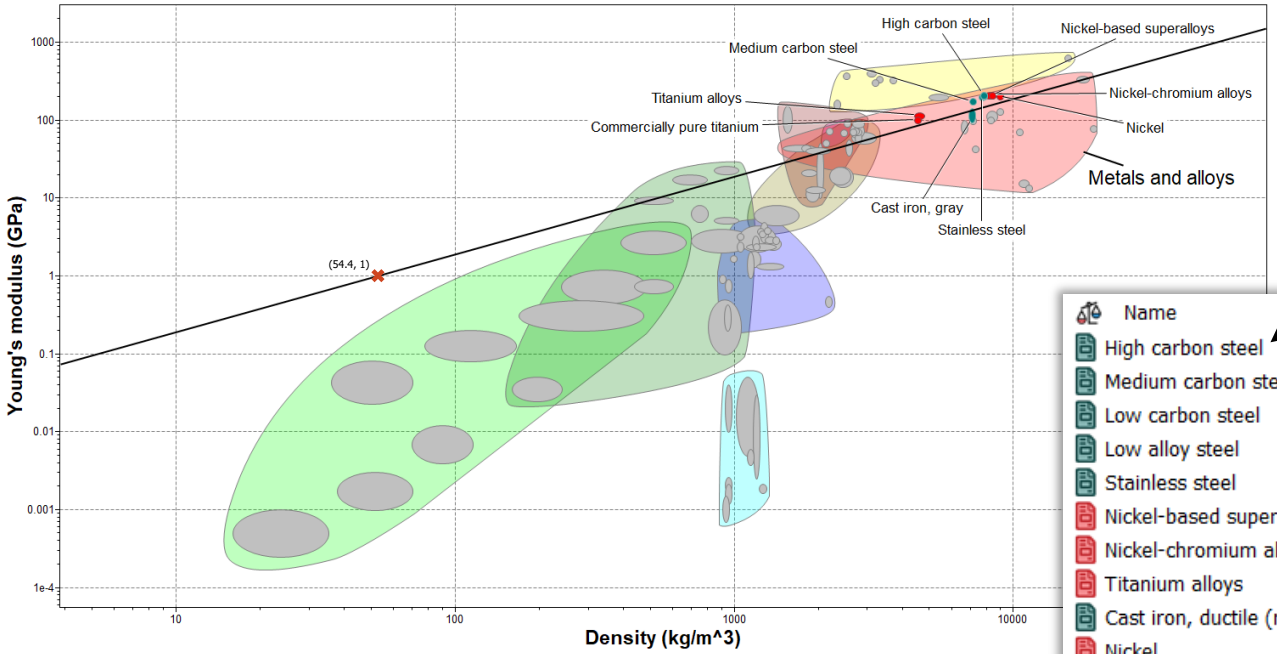
Material Index: $M = \frac{E}{\rho}$

$\leq 54.4 \frac{kg}{m^3}$ per 1GPa

For ≤1mm Deflection: $0.01 \geq \frac{3(9.8)}{.04^2} * \frac{\rho}{E}$ $\qquad \frac{\rho}{E} \leq 5.44 \times 10^{-7}$

Material Selection: The Verdict

- ✓ ≤1mm deflection
- ✓ Less than 1.5kg
- ✓ High stiffness
- ✓ Hard but not brittle



Tamahagane!

"jewel steel"

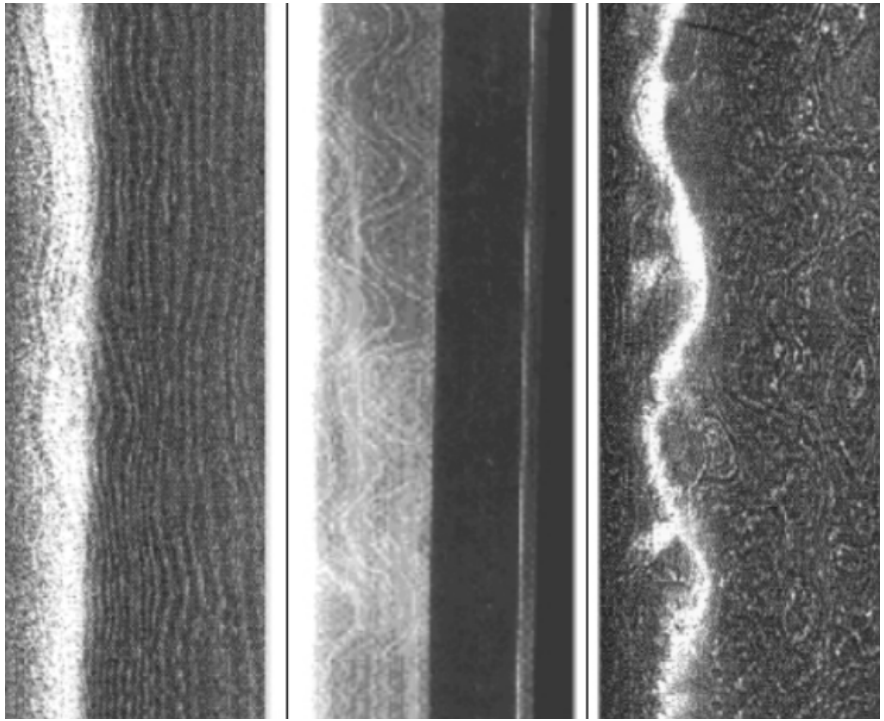
Name	Stage 1: Index, slope = 1
High carbon steel	0.0269
Medium carbon steel	0.0269
Low carbon steel	0.0269
Low alloy steel	0.0263
Stainless steel	0.0258
Nickel-based superalloys	0.0254
Nickel-chromium alloys	0.025
Titanium alloys	0.0249
Cast iron, ductile (nodular)	0.0246
Nickel	0.023
Commercially pure titanium	0.0227
Cast iron, gray	0.0162

Tamahagane

- Formed in a Japanese “tatara”, effectively a clay blast furnace
- Iron mined from sand deposits provided the ore, and the clay walls produced the slag
- For every 5kg of ore, only 1kg of bloom was produced
- Tamahagane is located on the raised outer edge of the bloom

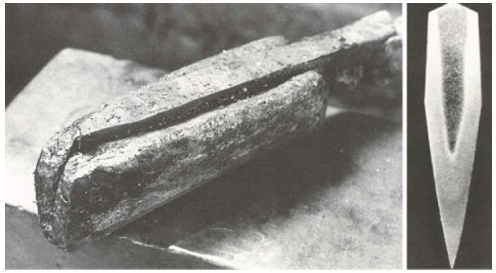
Tamahagane

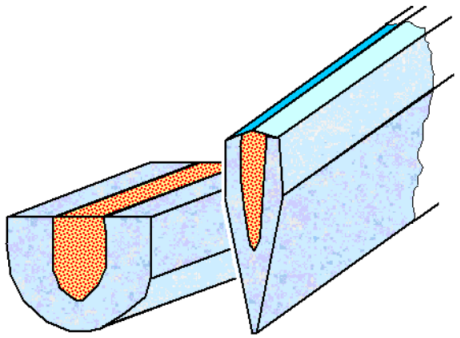
- The brittleness of the bloom helps distinguish high- from medium- and low-carbon steel
- Sorted pieces are hammer welded together
- Larger pieces homogenized by folding about 10 times (1024 layers)

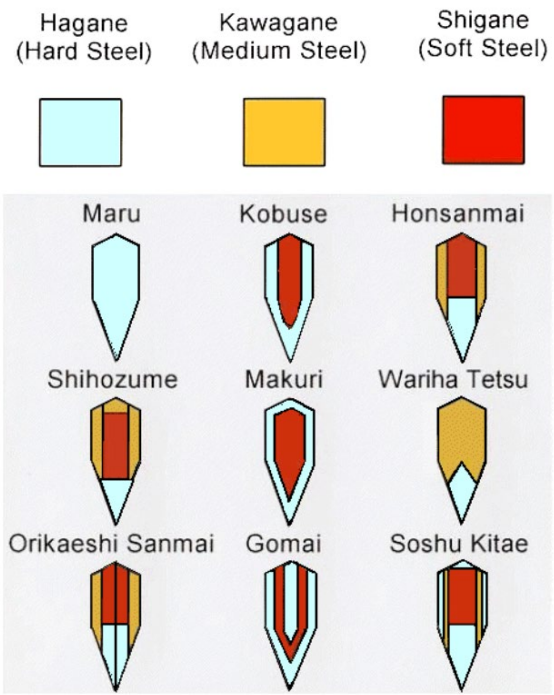


Forging a Blade

- Begin by hammering each steel into a rough shape
- Fire weld and hammer into the desired shape, except for the curvature
- Semi-finish by filing and grinding before quenching
- Softer steel in the back helps absorb impacts

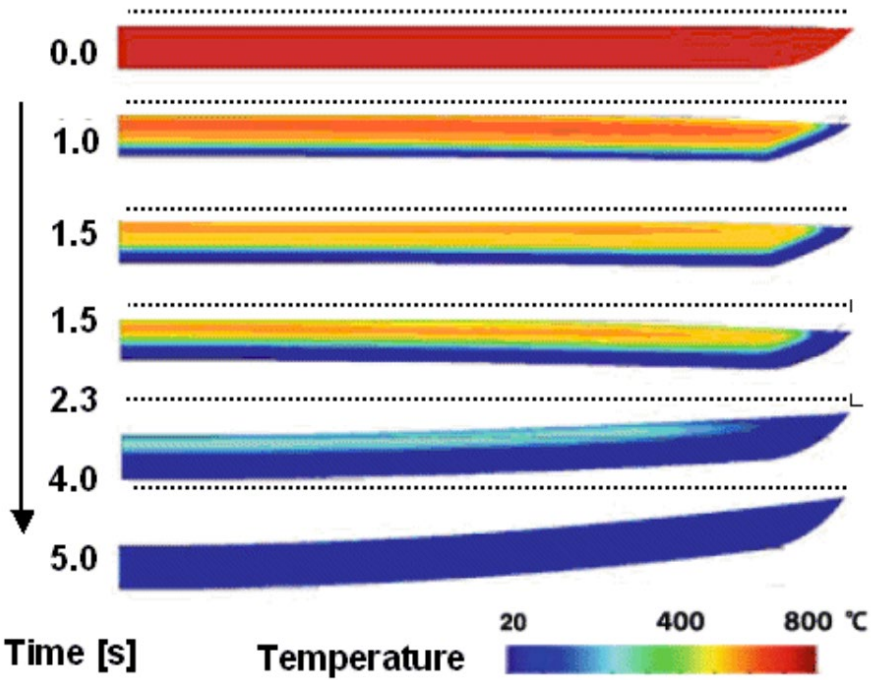






Quenching a Blade

- Quenching tamahagane brings the blade to a hardness of 800 VH (H_V~2.4GPa!)
- Differential cooling required to prevent overwhelming brittleness
- Phase changes at the blade result in volume changes which result in the final curved geometry



Summary

- Swords were previously made of copper and bronze but are now made of steel
- Tamahagane is the premier blade material
- Crafting a blade made from tamahagane is a significant undertaking
  - Single-use tatara furnaces
  - Multiple steels involved in forging
  - Complex quenching procedure

“The history of the sword is the history of mankind”

- Sir Richard Francis Burton,1884