Metallurgy of Steel

An introduction for knife making

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Outline

- Introduction
- Allotropy and polymorphism
- Iron-Carbon Diagram and steel microstructures
- Heat treatment and diagram TTT
Introduction

- Metallurgy is the art of working with metals.
- How do we transform our metal plate into a sharp knife?
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- Metallurgy is the art of working with metals.

- How do we transform our metal plate into a sharp knife?

What we are going to focus about:

- Iron ore, coke and additives
- Blast furnace smelting and segregating impurities
- Refining, casting and homogenization
- Forming, laminating and spheroidize annealing
- Machining and heat treatment
Allotropy and Polymorphism

- Allotropy: the property of an element to exist in more than one solid form (called allotropes).
- Polymorphism: the property of compounds to exist in more than one solid form (called polymorphs).
- Different allotropes/polymorphs exist at various pressures and temperatures.
- The allotropes/polymorphs can be stable or metastable.

Allotropes of carbon
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Diamond: metastable for room temperature and pressure

Graphite: stable form of carbon at room temperature and pressure

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We obtain diamond by compressing and heating graphite.

Quick cooling and releasing “traps” carbon in a diamond configuration
Iron-Carbon diagram and steel microstructures

What about Steel?

- Steel is an alloy and contain two main constituents: iron and carbon.
- It is a compound and has different polymorphic states, related to its microstructure.

As many metals, steel is a polycrystalline material, composed of grain and inclusions.
Iron-Carbon diagram and steel microstructures

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Iron-Carbon diagram and steel micostructures

What about our steel?

The Knife making course uses a **1095 carbon steel**:

- **Between 0.9-1.03 % carbon**

- **0.3-0.5% manganese**: for hot working and increase in strength, toughness and hardenability

- **0.01% max impurities such as sulfur and phosphorus** that improves machinability

Properties: high hardness and strength, poor machinability and can be brittle, used in tools with sharp cutting edges
Iron-Carbon diagram and steel microstructures

What about our steel?

1095 carbon steel has different microstructures according to temperature:

From room temperature to 1333°F, the steel is formed by a compound of iron and iron carbide (ceramic). Because of how it looks, it is called Perlite and Cementite:

- Perlite: 20µm, 240 Brinell
- Cementite: 20µm, 550 Brinell
Iron-Carbon diagram and steel microstructures

What about our steel?

1095 carbon steel has different microstructures according to temperature:

Past 1333 F, carbon start dissolving in iron and creates austenite. Around 1450 F carbon is completely dissolved in iron, there is no carbide left. Austenite is paramagnetic.
Why do we care about microstructures at high temperatures?

Pure iron is too soft for sharp tools. Carbides are hard and brittle. We would like to have better properties for knife making.

How do you think we can do that?
Iron-Carbon diagram and steel microstructures

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Heat treatment!
Heat treatment and diagram TTT

- Heat up the steel past the Curie temperature (~1450 F)
- Quickly cool down the steel to “trap” the carbon in iron lattice. This is called **quenching**
- This creates **martensite**, a hard new microstructure that is a metastable form of steel:

![Diagram showing TTT transformation temperatures and phases](image_url)

**TTT Diagram**

- Liquid phase
- Austenite+ molten steel
- Austenite
- Austenite+Fe3C
- Ferrite+Fe3C
- Up to 770 Brinell !!
Heat treatment and diagram TTT

- Martensite is brittle
- A tempering annealing is done to relax the residual constraints
- The tempering is done at a temperature lower than 1333

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Up to 770 Brinell !!
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A tempering annealing is done to relax the residual constraints.

Tempering is done at a temperature lower than 1333 F.

Temperature and time of tempering are selected as a trade-off between hardness and brittleness.
How to select parameters for quenching and tempering our steel?

TTT diagram of 1095 carbon steel:

-technique 1: full quenching in water then tempering to have a mix of martensite and bainite (iron+iron carbide)

-technique 2: better control on temperature to directly have the right tempered martensite, e.g. using appropriate oil
Conclusion

Let's get to work!