Metallurgy of Steel

An introduction for knife making

By: Yan Azdoud, Ph.D.

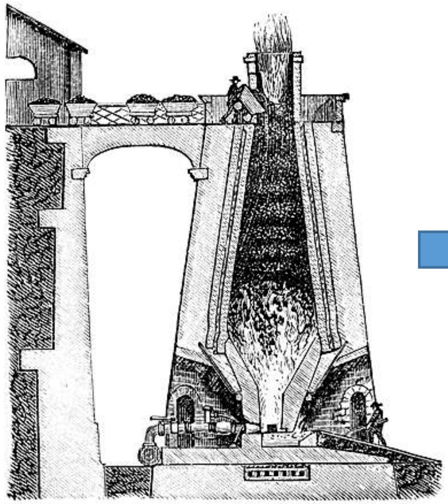
Outline

- Introduction
- Allotropy and polymorphism
- Iron-Carbon Diagram and steel micostructures
- 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?

Iron ore, coke and additives



Blast furnace smelting and segregating impurities

Refining, casting and homogenization

Forming, laminating and spheroidize annealing

Machining and heat treatment

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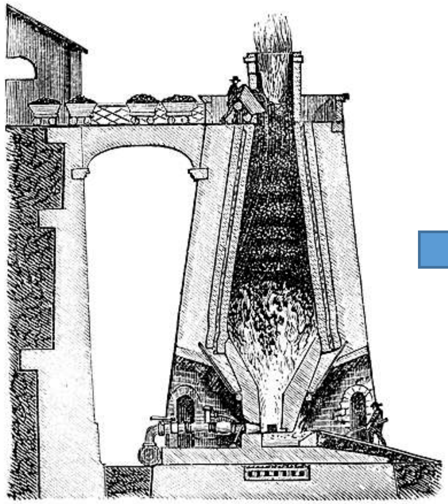


Blast furnace smelting and segregating impurities

Refining, casting and homogenization

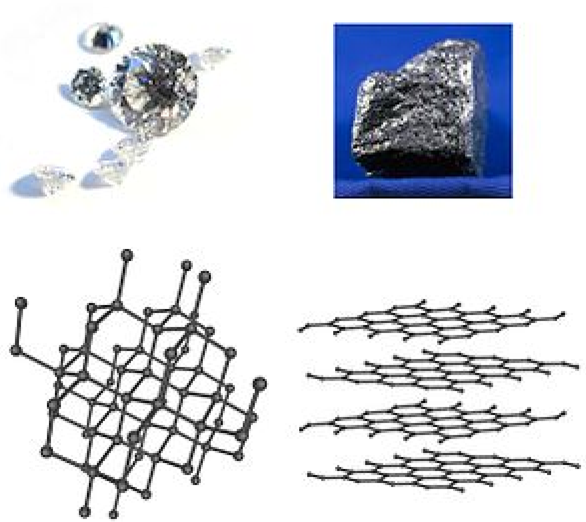
What we are going to focus about

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 polymophs).
- Different allotropes/polymorphs exist at various pressures and temperatures.
- The allotropes/polymorphs can be stable or metastable.



Allotropes of carbon

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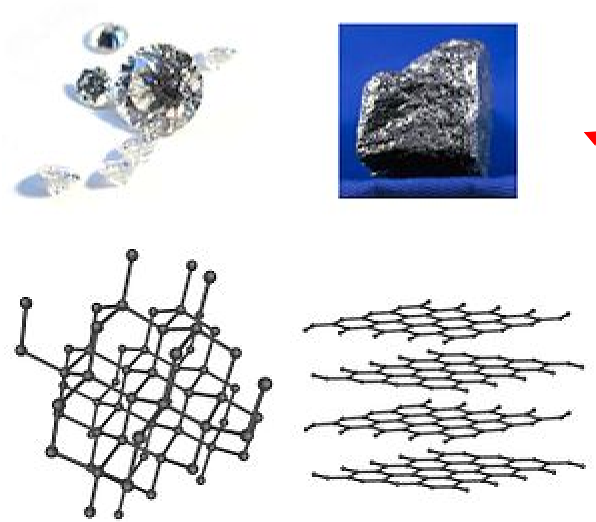
Diamond: metastable for room temperature and pressure



Graphite: stable form of carbon at room temperature and pressure

Allotropes of carbon

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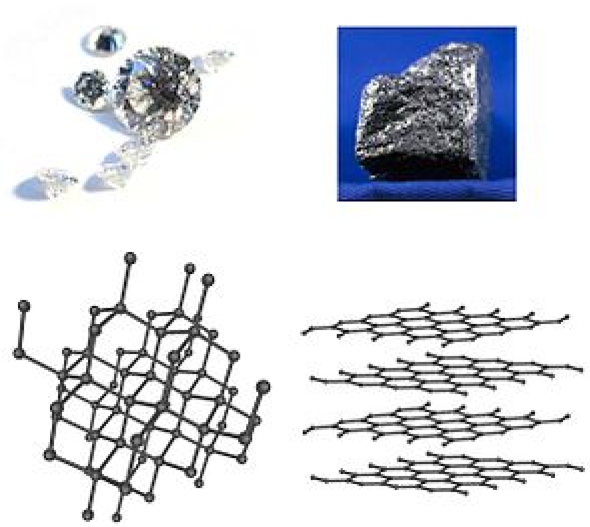
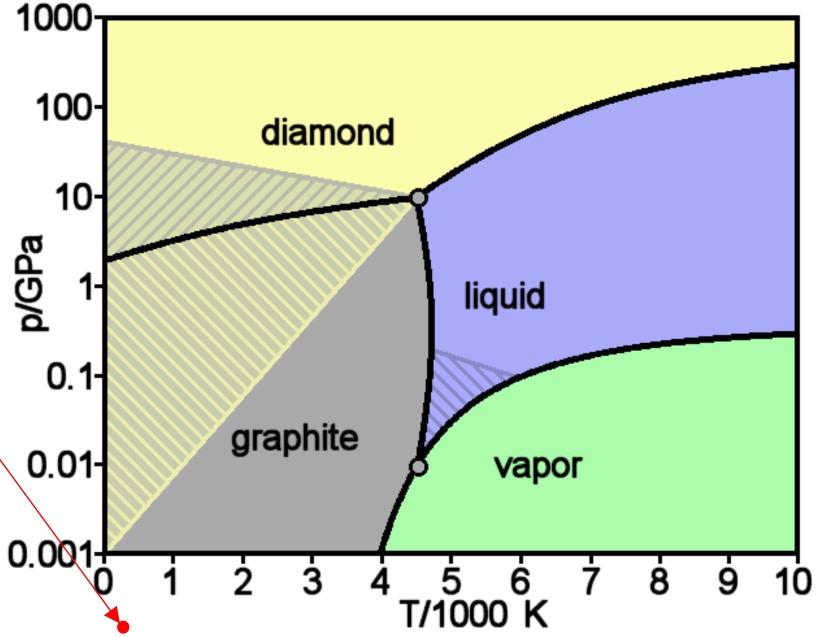


Allotropes of carbon

pressure

We are here !



temperature

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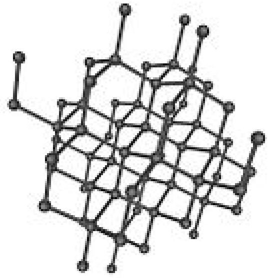
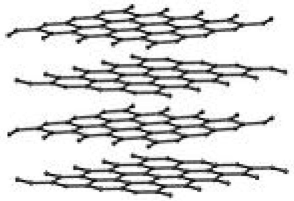

Allotropes of carbon

pressure

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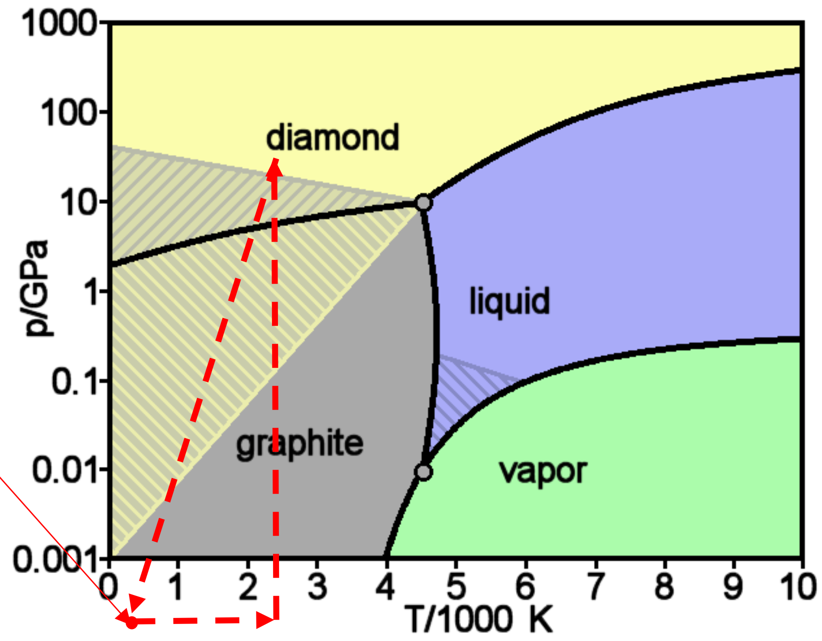


temperature

We obtain diamond by compressing and heating graphite.

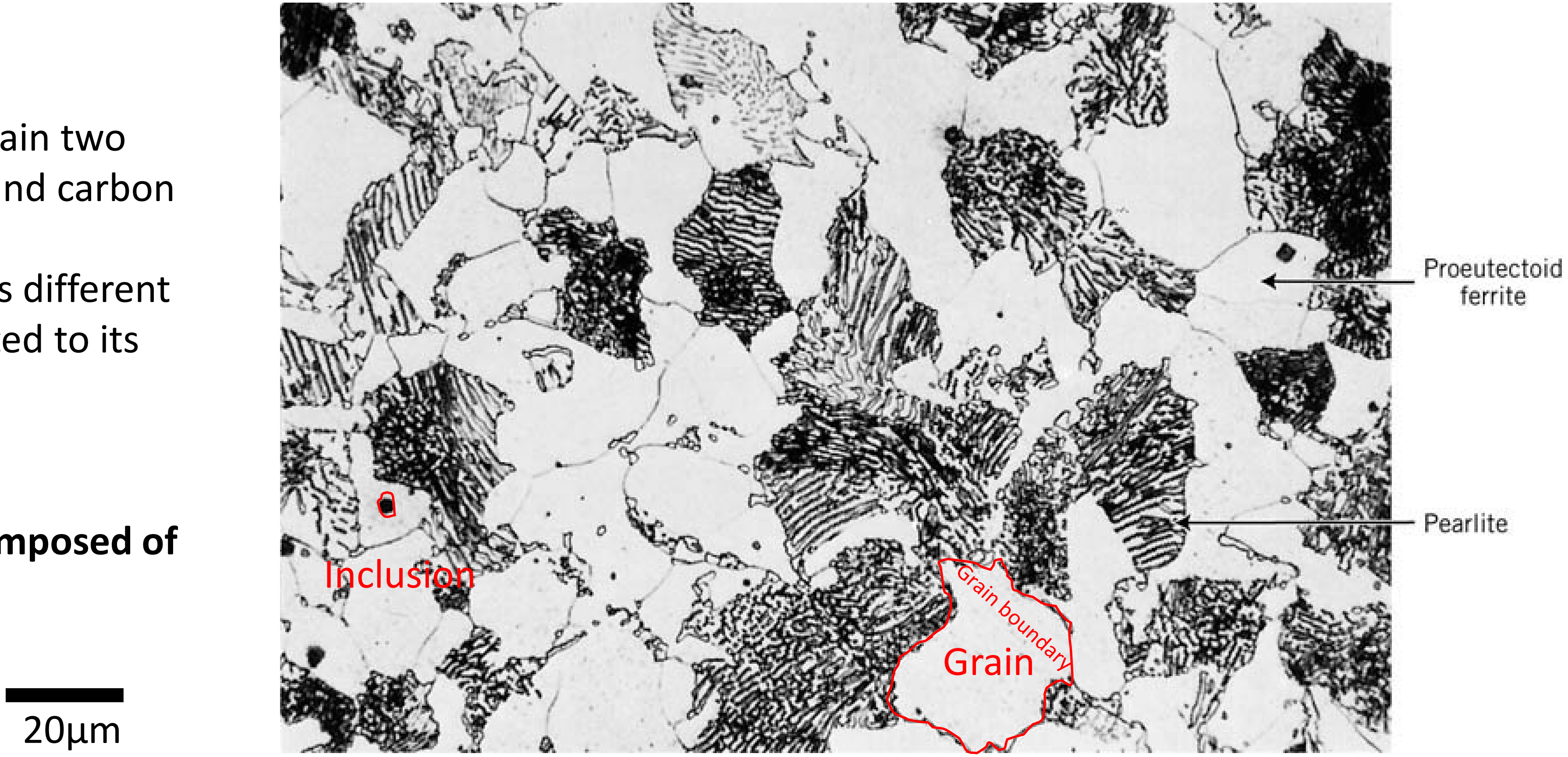
Quick cooling and releasing "traps" carbon in a diamond configuration

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.



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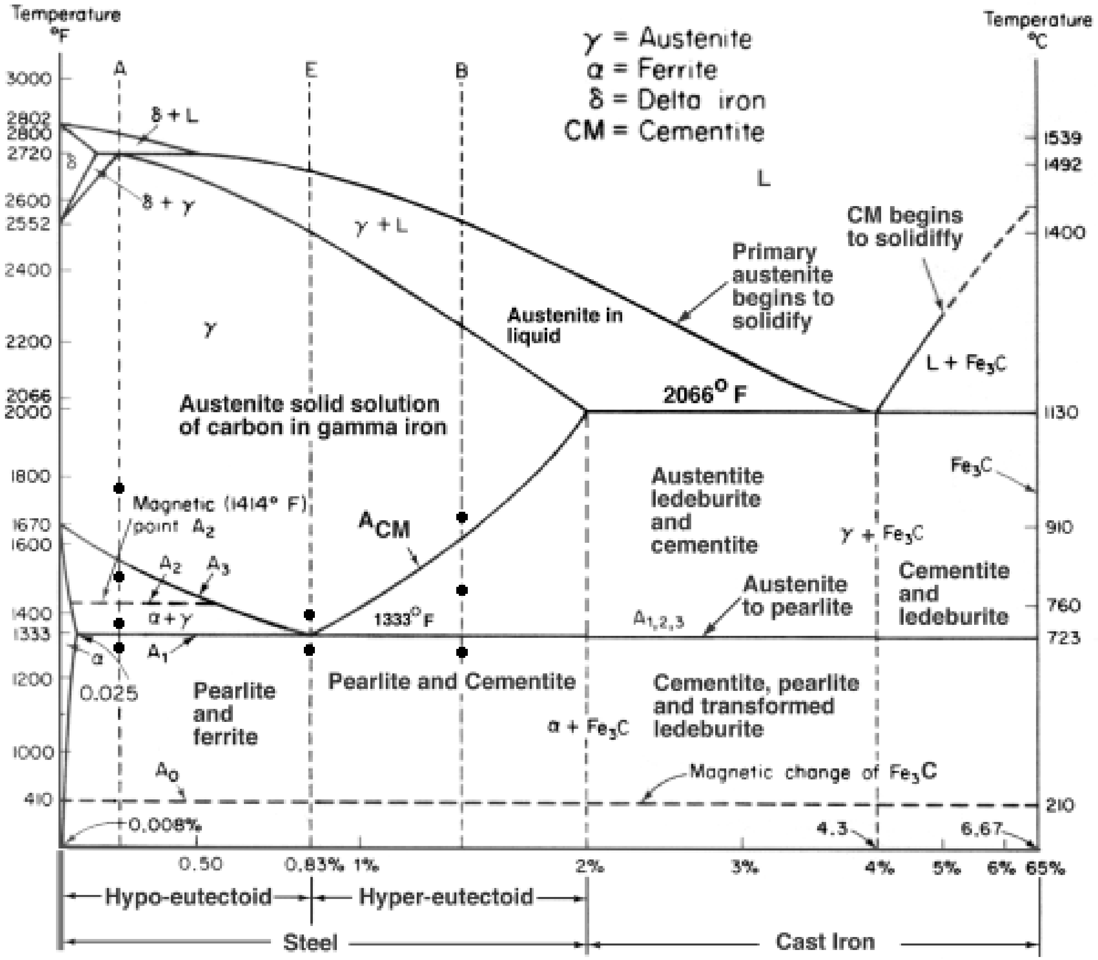
Since we don't care about pressure we are going to use an iron carbon phase diagram:



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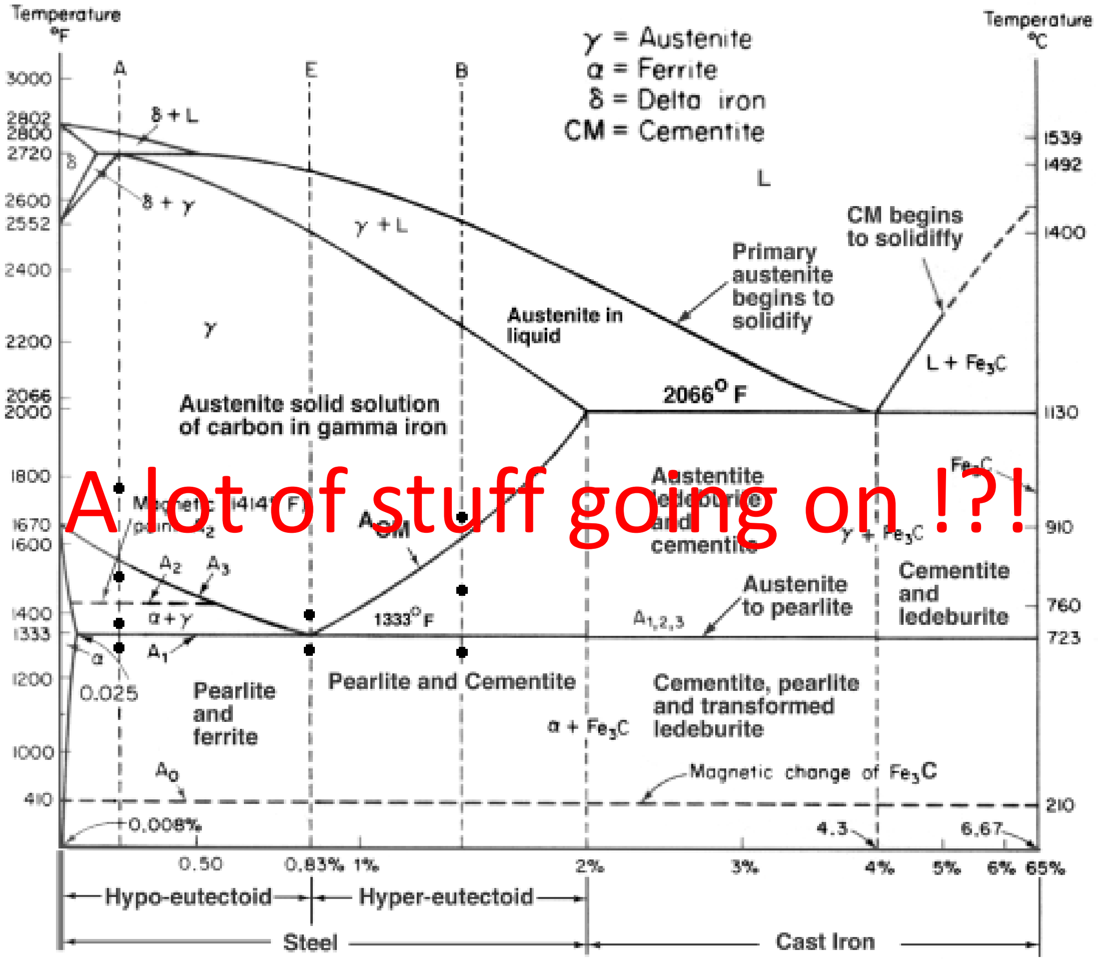


Iron-Carbon diagram and steel micostructures

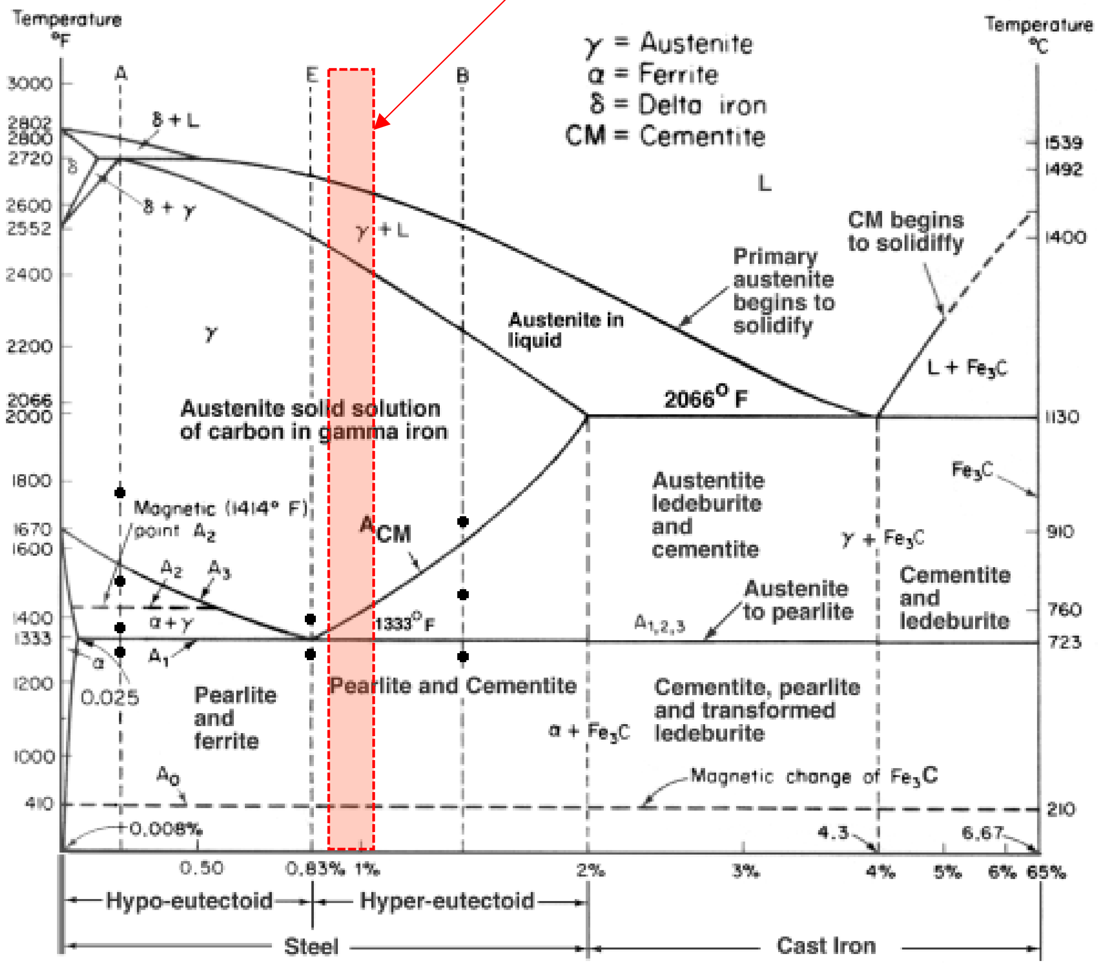
What about our steel?

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

Zone of interest

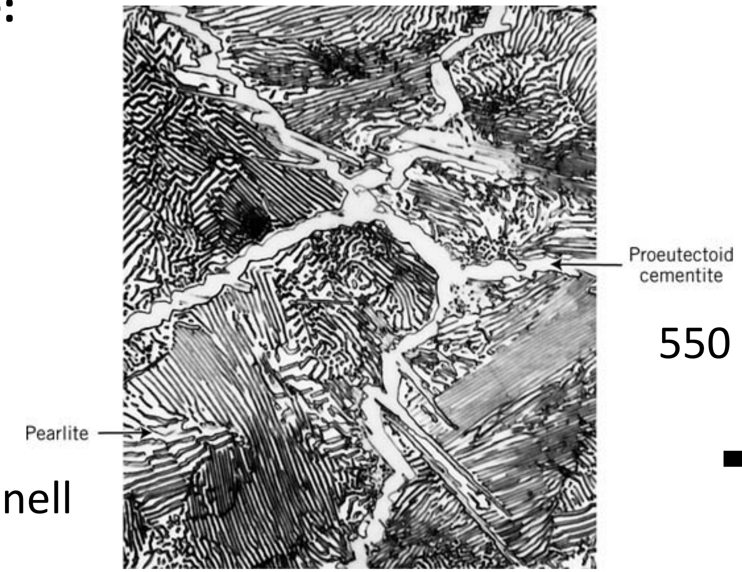


Iron-Carbon diagram and steel microstructures

What about our steel?

1095 carbon steel has different microstructures according to temperature:

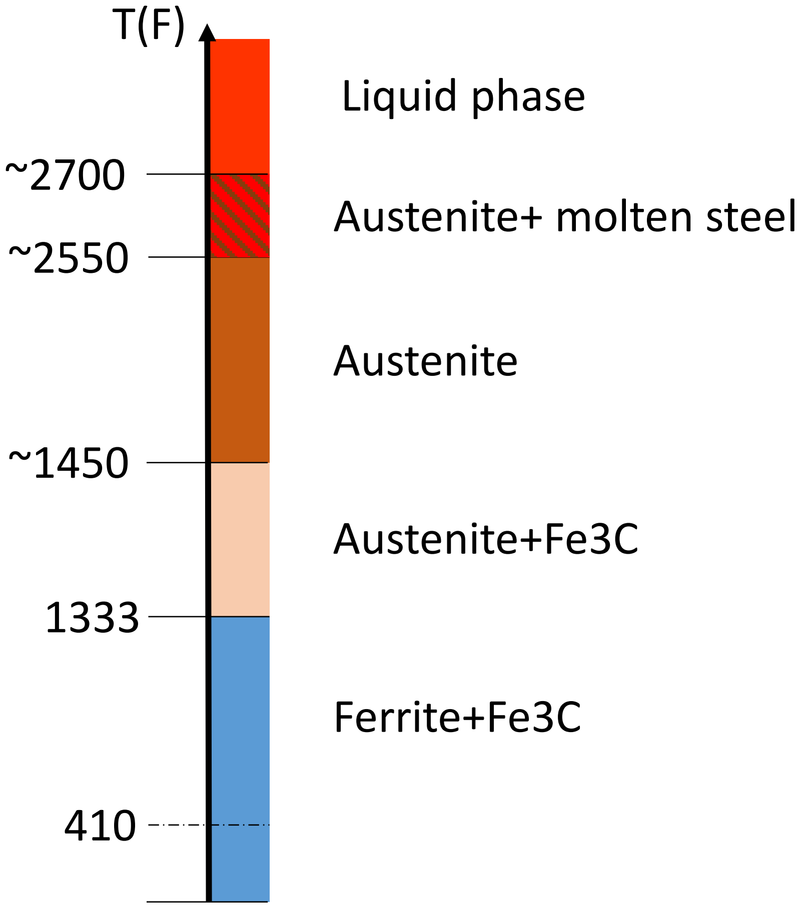
From room temperature to 1333 F, the steel is formed by a compound of iron and iron carbide (ceramic). Because of how it looks, it is called Perlite and Cementite:



550 Brinell

240 Brinell

20µm

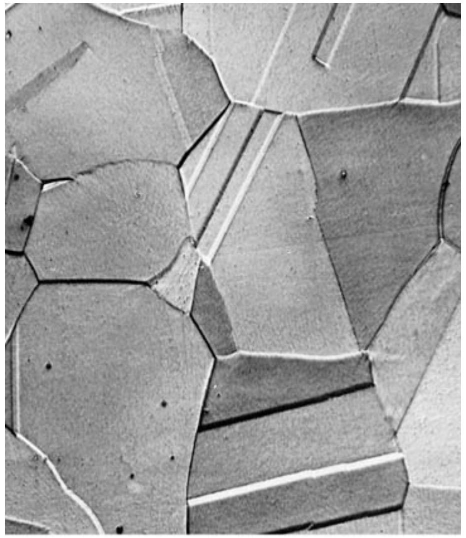


Iron-Carbon diagram and steel microstructures

What about our steel?

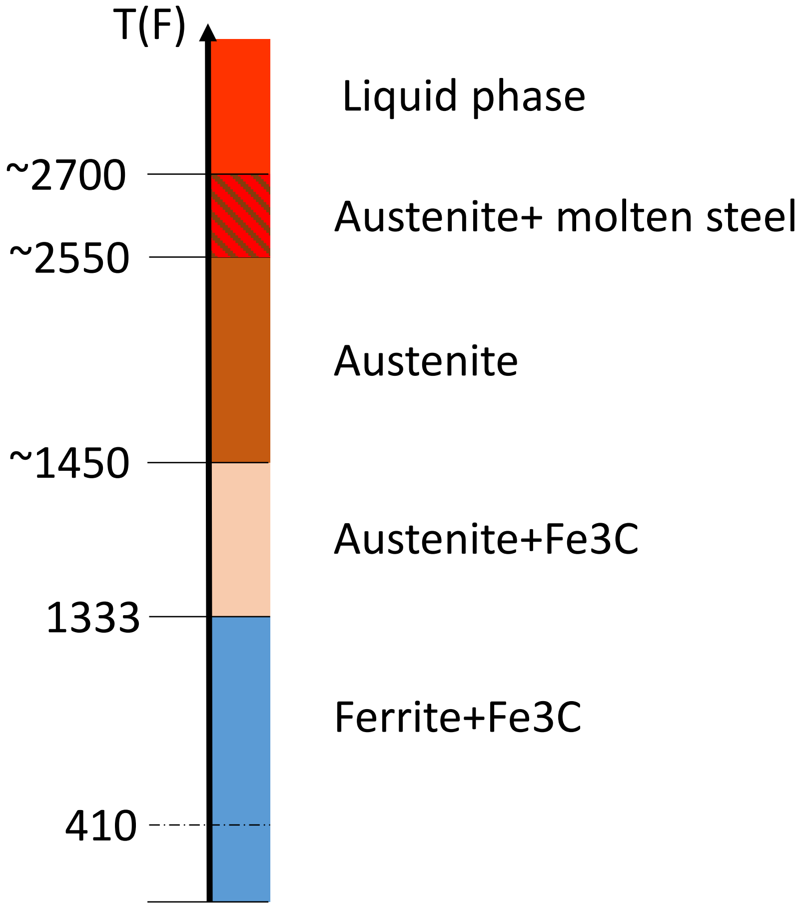
1095 carbon steel has different microstructures according to temperature:

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.



20µm

(b)

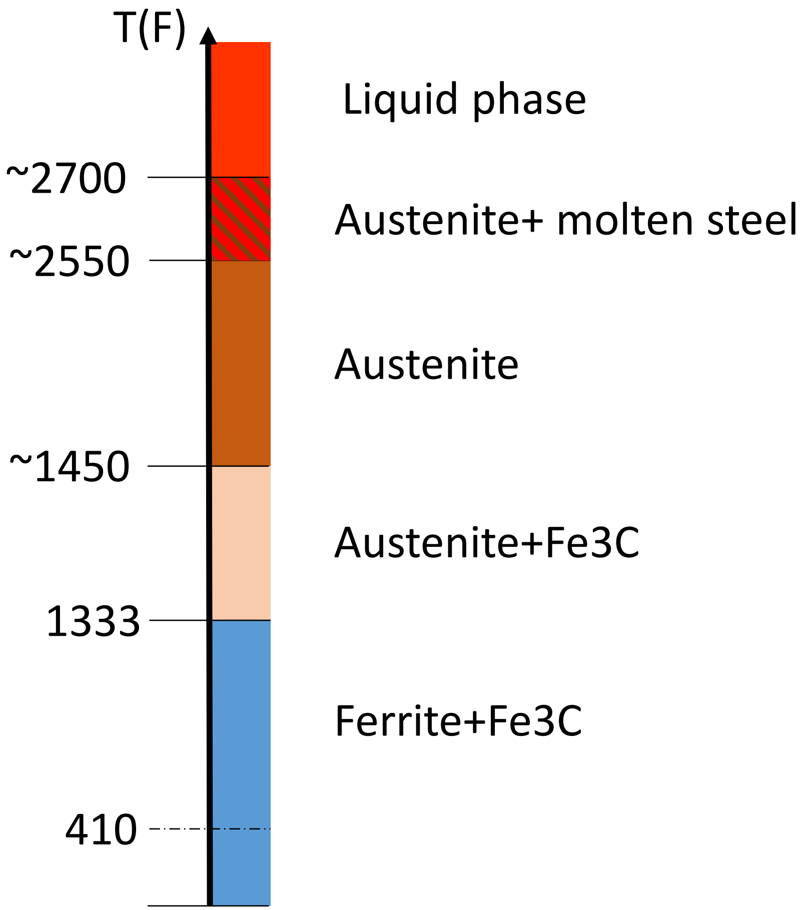


Iron-Carbon diagram and steel microstructures

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?



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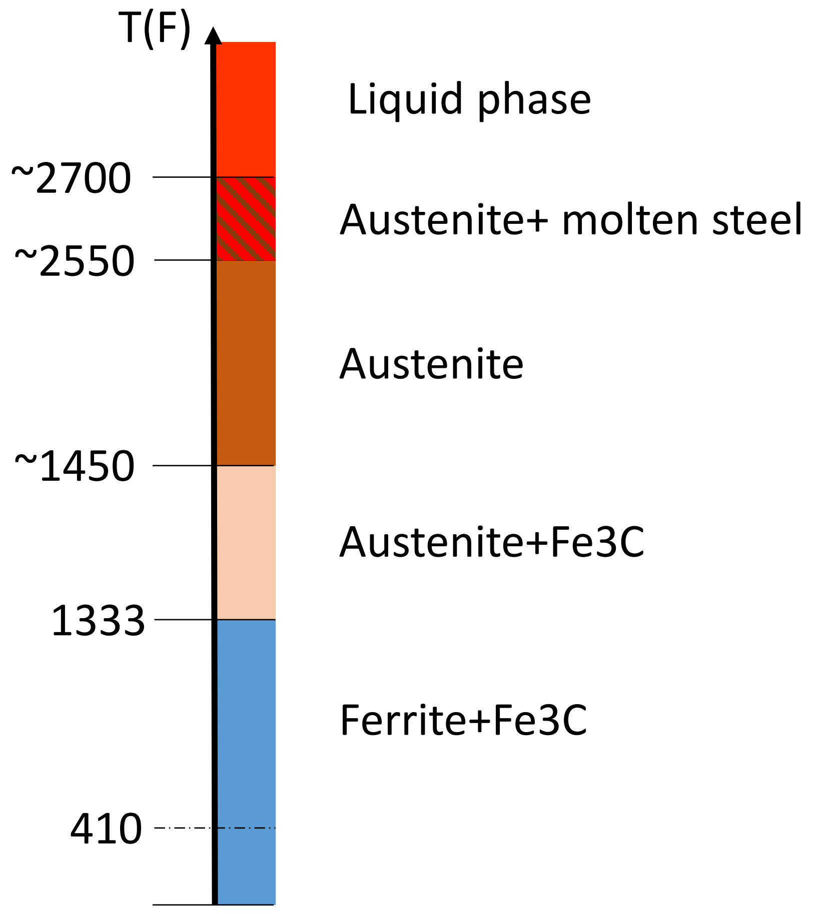
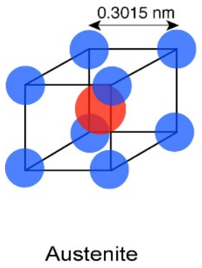


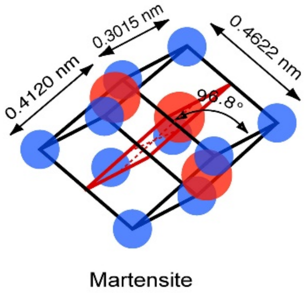
Heat treatment !

Heat treatment and diagram TTT

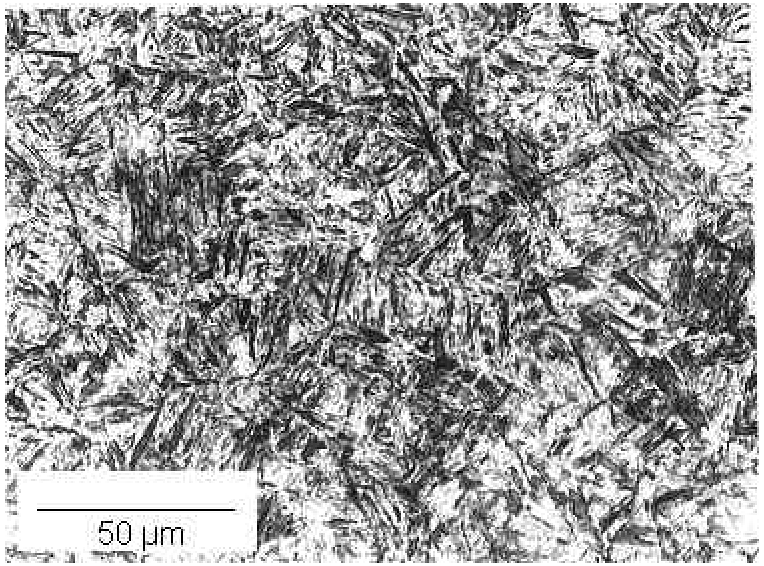
- Heat up the steel past the Curie temperature (~1450 F)
- Quickly cool down the steal to “trap” the carbon in iron lattice. This is called **quenching**
- This creates **martensite,** a hard new microstructure that is a metastable form of steel:



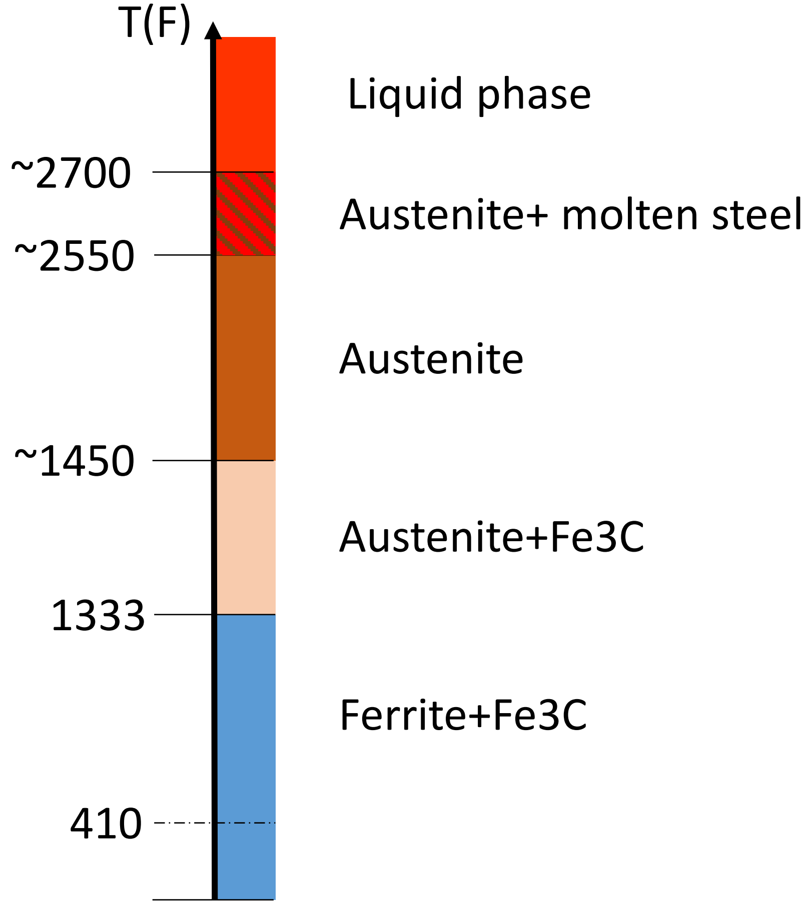
FCC



BCT

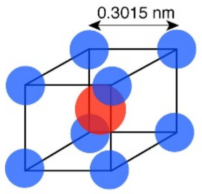


Up to 770 Brinell !!



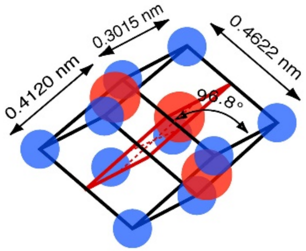
Heat treatment and diagram TTT

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



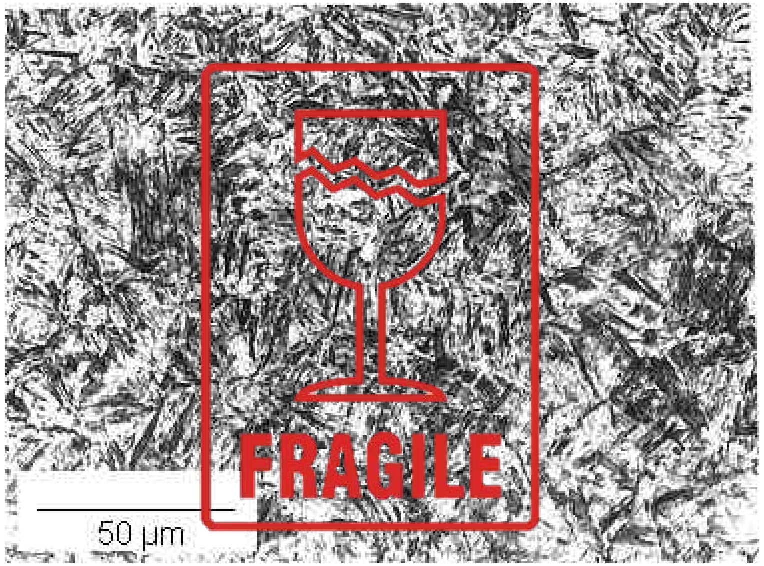
Austenite

FCC



Martensite

BCT



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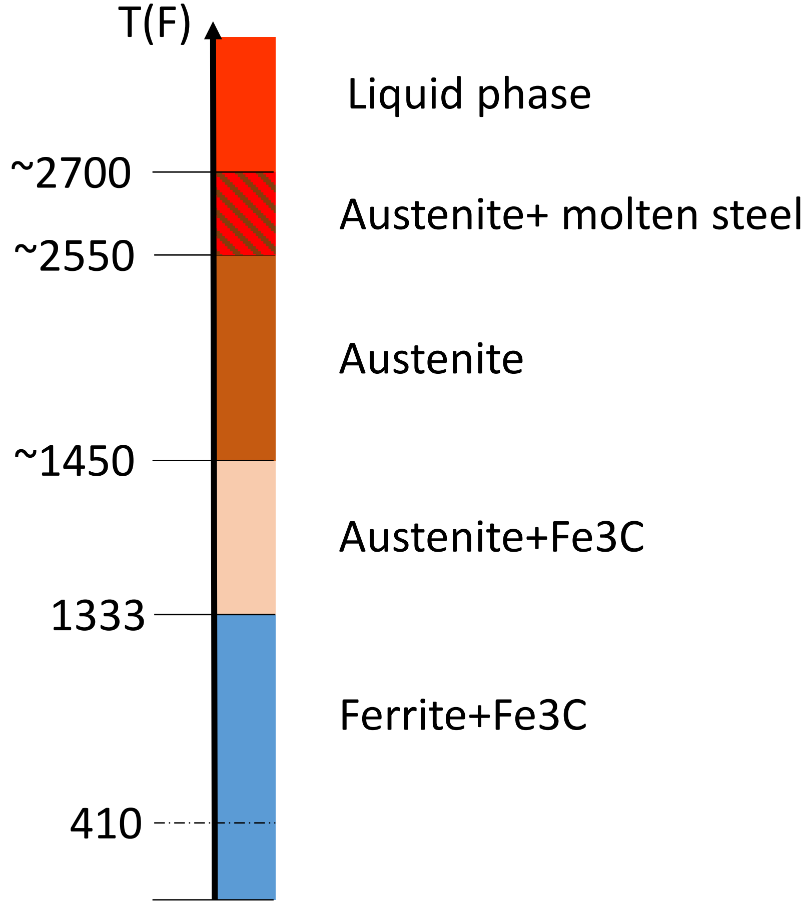
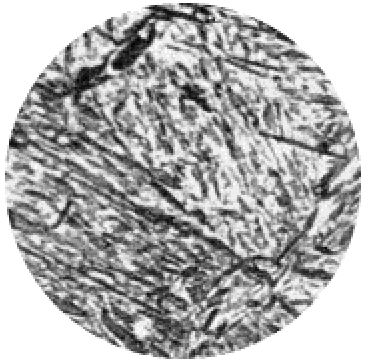


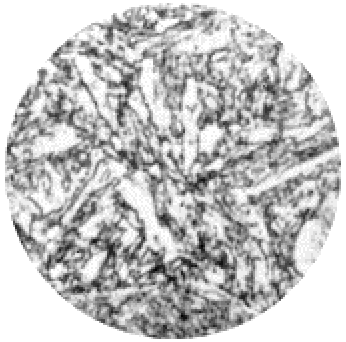
Heat treatment and diagram TTT

- Martensite is brittle
- 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 a selected as a trade-off between hardness and brittleness



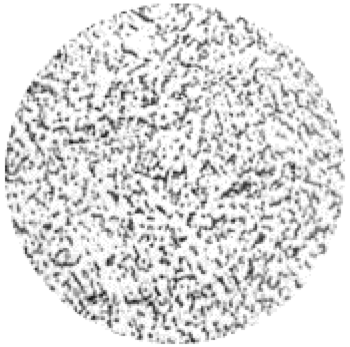
Martensite

Hard and brittle



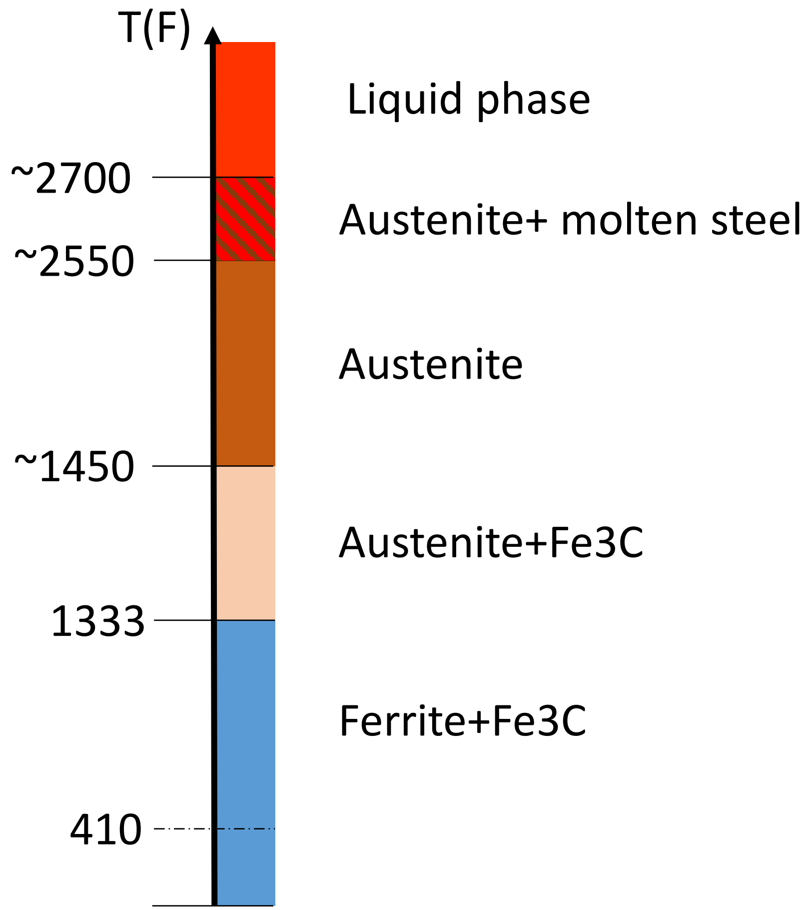
Tempered Martensite

Balanced



Heavily Tempered

Soft and ductile



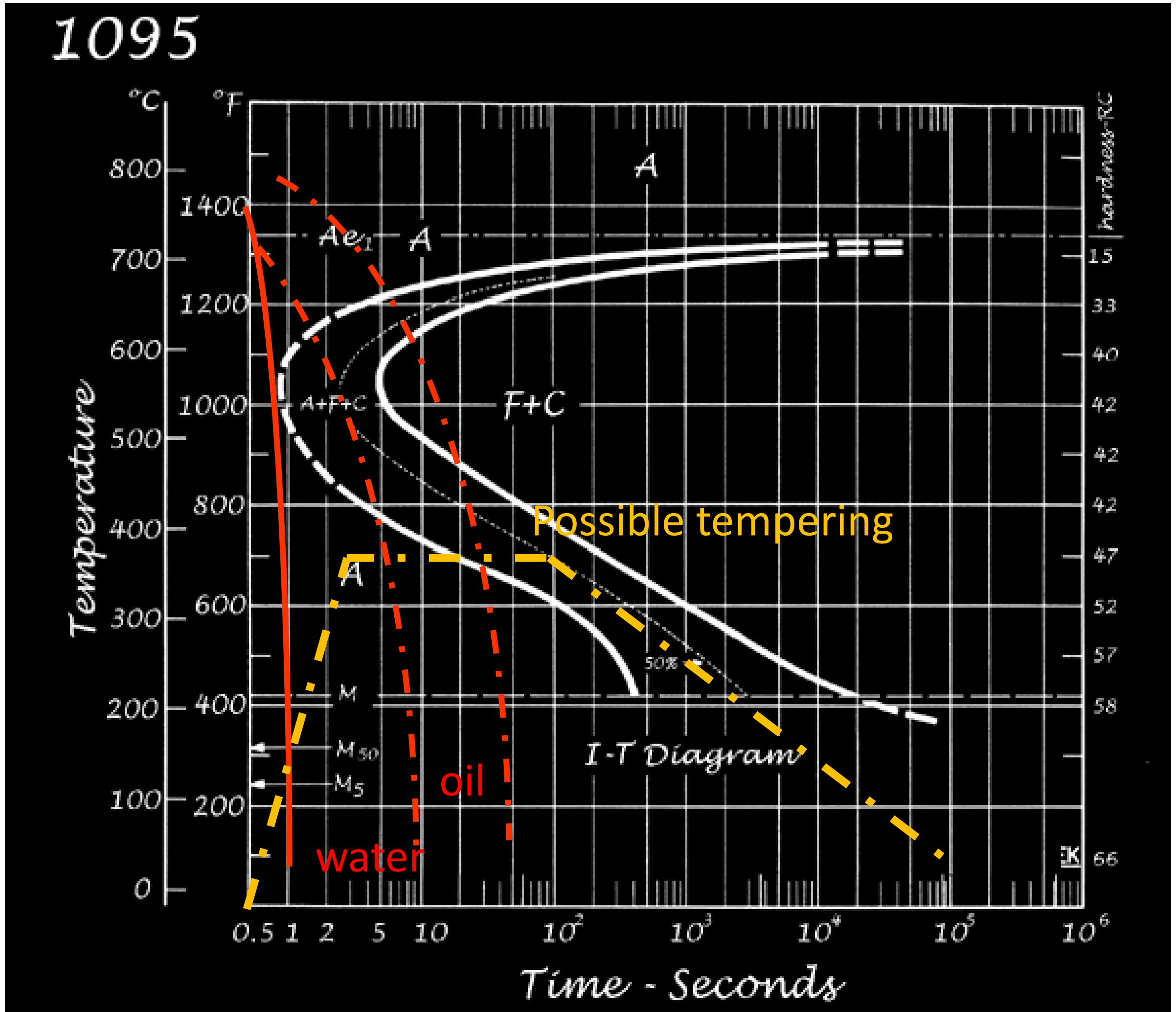
Heat treatment and diagram TTT

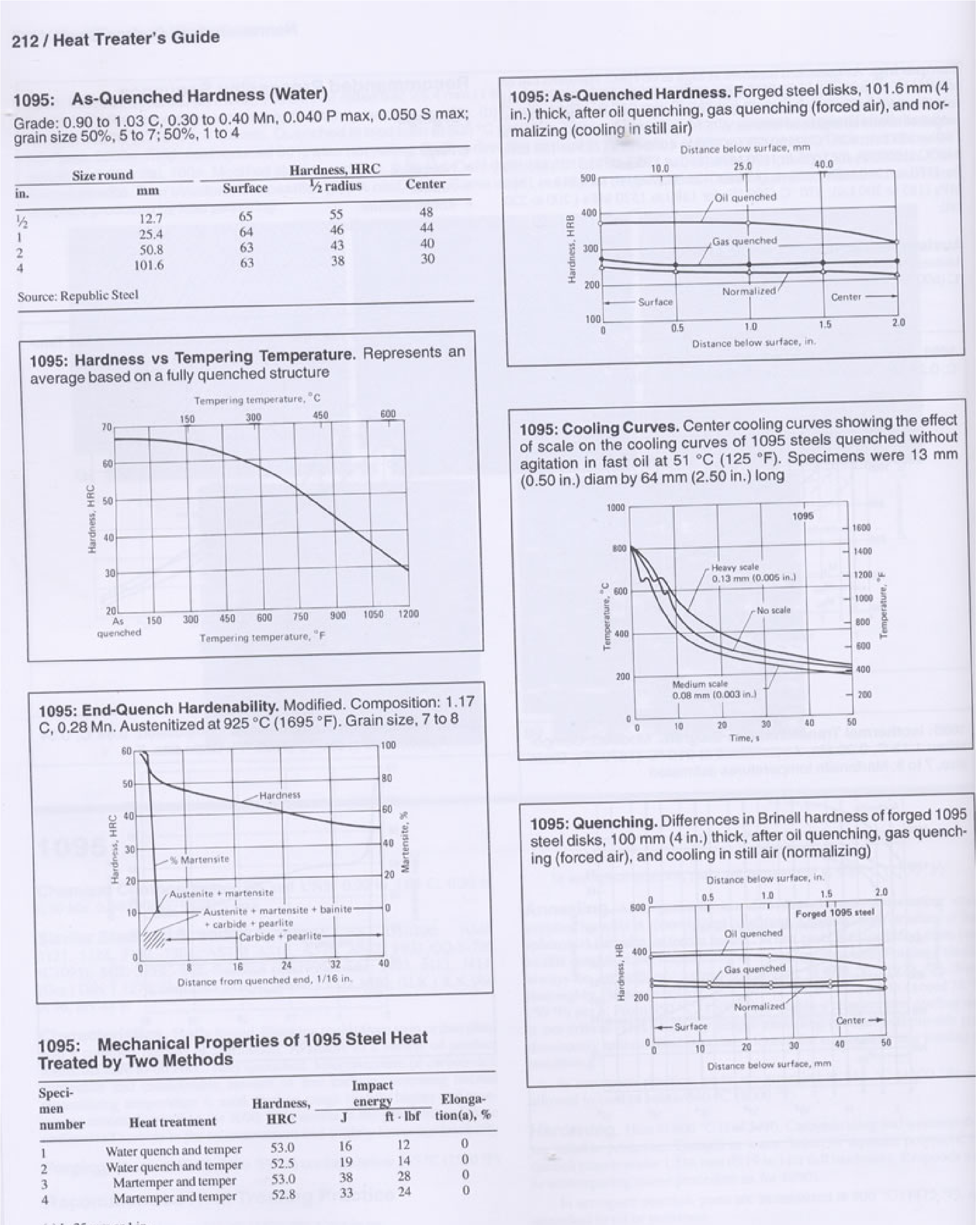
How to select parameters for quenching and tempering our steel?

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





1095: As-Quenched Hardness (Water)

Grade: 0.90 to 1.03 C, 0.30 to 0.40 Mn, 0.040 P max, 0.050 S max; grain size 50%, 5 to 7; 50%, 1 to 4

Size round, in.	Size round, mm	Hardness, HRC: Surface	Hardness, HRC: ½ radius	Hardness, HRC: Center
½	12.7	65	55	48
1	25.4	64	46	44
2	50.8	63	43	40
4	101.6	63	38	30

Source: Republic Steel

1095: Hardness vs Tempering Temperature. Represents an average based on a fully quenched structure

1095: End-Quench Hardenability. Modified. Composition: 1.17 C, 0.28 Mn. Austenitized at 925 °C (1695 °F). Grain size, 7 to 8

1095: Mechanical Properties of 1095 Steel Heat Treated by Two Methods

Specimen number	Heat treatment	Hardness, HRC	Impact energy, J	Impact energy, ft · lbf	Elongation(a), %
1	Water quench and temper	53.0	16	12	0
2	Water quench and temper	52.5	19	14	0
3	Martemper and temper	53.0	38	28	0
4	Martemper and temper	52.8	33	24	0

1095: As-Quenched Hardness. Forged steel disks, 101.6 mm (4 in.) thick, after oil quenching, gas quenching (forced air), and normalizing (cooling in still air)

1095: Cooling Curves. Center cooling curves showing the effect of scale on the cooling curves of 1095 steels quenched without agitation in fast oil at 51 °C (125 °F). Specimens were 13 mm (0.50 in.) diam by 64 mm (2.50 in.) long

1095: Quenching. Differences in Brinell hardness of forged 1095 steel disks, 100 mm (4 in.) thick, after oil quenching, gas quenching (forced air), and cooling in still air (normalizing)

Conclusion

Lets get to work!