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ENR116 Engineering Materials

Module 3 Metals

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Alloy fabrication and processing

ENR116 – Mod. 3- Slide No. 4

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Intended Learning Outcomes

At the end of this section, students will be able to:-

- Identify some of the common alloy fabrication techniques.
- Describe some of the commonly employed heat treatment procedures used to improve the mechanical properties of materials.

At the end of this lecture summary you will be able to identify some of the commonly used fabrication techniques and heat treatment procedures applied to metals.

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Alloy classifications

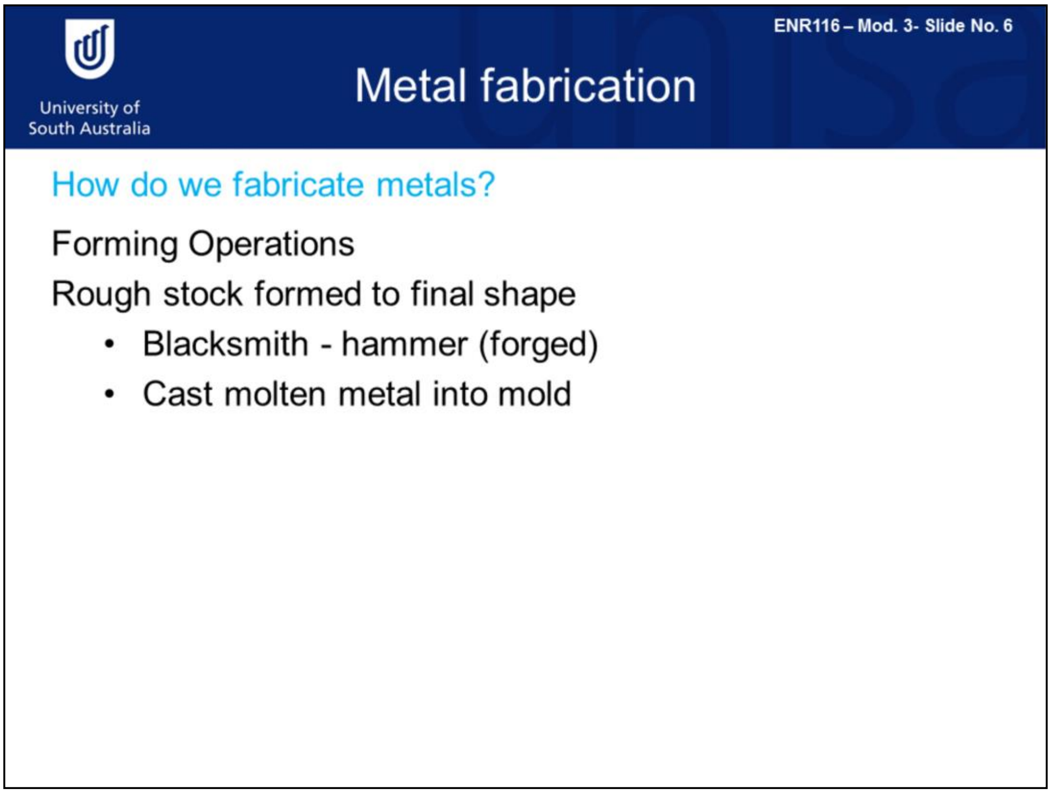
Alloy Class	Advantages	Examples
Cast Irons	Inexpensive.	White, Gray, Ductile Malleable.
Steels	Large range of strengths, ductility's.	1016 Plain carbon steel, CA6N chromium-nickel steel
Nonferrous	Electrical conductivity. Corrosion resistance. High strength: weight ratio.	Noble metals, titanium, copper and aluminium alloys.

•Before we start this lecture summary it is worth considering the general classifications of alloys and the uses.

•Cast irons are inexpensive but limited in their mechanical performance.

•Steels are numerous, have many potential alloying elements and are widely applied where neither a high strength to weight ration or corrosion resistance are requirements.

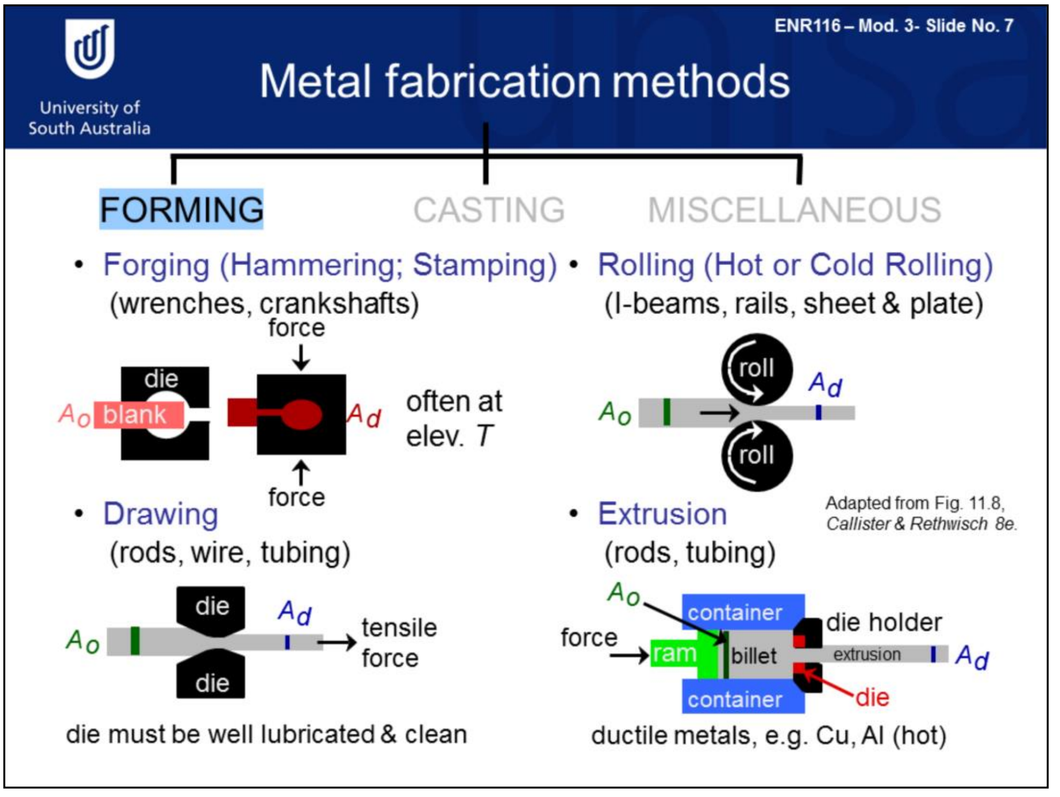
•For these applications there are many nonferrous alloys with a range of unique mechanical properties.



•Metal fabrication can be described in a number of ways. Often it know as forming where the metal is formed, by application of some external force, into the final shape.

•This forming or processing can be categorised as either hot or cold working. Cold working can still be at an elevated temp with the description hot or cold relating to the recrystallisation temp.

•Hot is a high enough temp for recrystallisation to occur whilst cold working relies on strain hardening as the microstructural processing step.



•The first fabrication processes to consider are those of forming.

•In each case an external force is applied which forms the metal.

•This force will then alter the microstructure and the workpieces mechanical properties either by deforming the grains, cold working, or by recrystallisation of the grains, hot working.

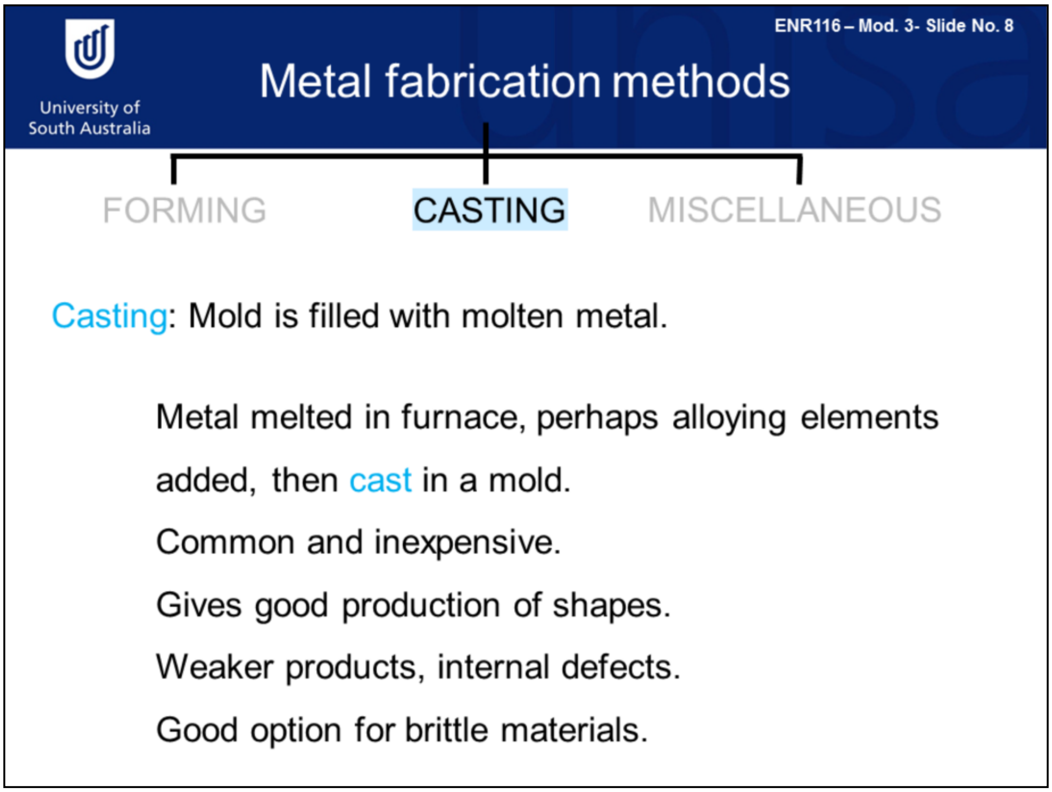
•Forging places a metal blank into an open mould and a compressive force is applied.

•Rolling places an often continuous slab of metal through rollers which cause the slab cross-section to be reduced.

•Similarly the drawing of rods, wire, etc. have the metal passing through dies to reduced the cross-section although in this instance the force applied is a tensile one.

•Finally we have extrusion which forces the metal through a die. Generally this is for hot, ductile metals as a great deal of force is required.

•These processes can be highly automated to keep fabrication costs low.



- The next type of fabrication is that of casting. This process almost exclusively uses molten metal.
- Here we can form complex finished shapes.
- For low ductile alloys i.e. brittle metals and alloys this provides an economical forming technique.

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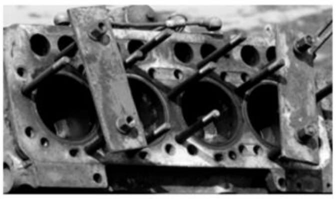
Metal fabrication methods

FORMING | **CASTING** | MISCELLANEOUS

Sand Casting: (large parts, e.g., auto engine blocks)



What material will withstand *T* >1600ºC and is inexpensive and easy to mold?

Answer: Sand

To create mold, pack sand around form (pattern) of desired shape.

•One of the cheapest and oldest casting techniques is sand casting where the mould is formed of sand i.e. silica particles.

•Large workpieces can be formed and reasonable fine details and structures can be cast.

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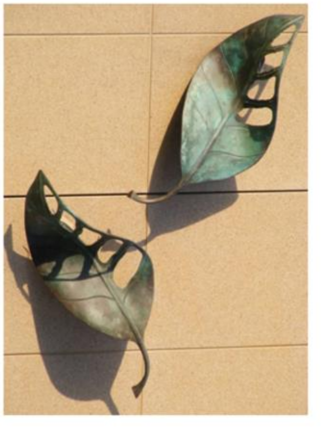
Metal fabrication methods

FORMING | **CASTING** | MISCELLANEOUS

Investment Casting: (low volume, complex shapes e.g., jewellery, turbine blades)

- Stage I — Mold formed by pouring plaster of paris around wax pattern. Plaster allowed to harden.
- Stage II — Wax is melted and then poured from mold—hollow mold cavity remains.
- Stage III — Molten metal is poured into mold and allowed to solidify.



•Where complex shapes with very fine structures need to be formed we look to use investment casting i.e. turbine blades, jewellery.

•This is still an old technique but it requires several steps which naturally makes it more expensive.

•Firstly the mould is formed by pouring plaster of paris around a previously modelled wax pattern or sculpture.

•Once the plaster has hardened the whole is heated to melt and pour off the wax.

•The molten metal is poured into the mould to form the workpiece.

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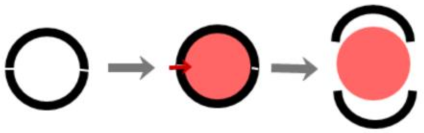
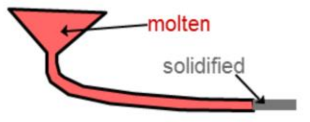
Metal fabrication methods

FORMING | **CASTING** | MISCELLANEOUS

Die Casting:
High volume.
For alloys having low melting Temperatures.



Continuous Casting:
Simple shapes (e.g., rectangular slabs, cylinders).



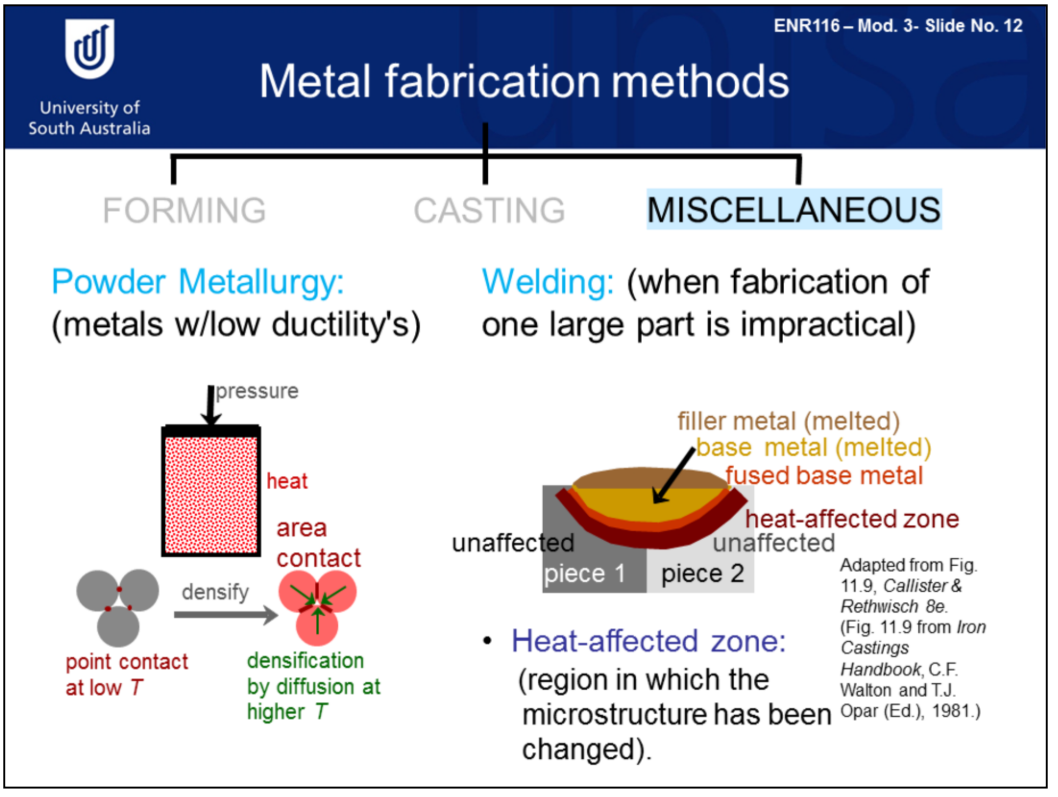
•Die casting is a variation on stamp forging where the mould in two parts is brought together around the molten metal charge.

•Can only be used for low melting temperature alloys but this is another high volume, high automation technique.

•The final form of casting is another which can be highly automated and that is continuous casting.

•This is the method primarily employed as the first forming stage after metal extraction and purification.

•Produces simple shapes with more uniform compositions and microstructure than ingots of material.



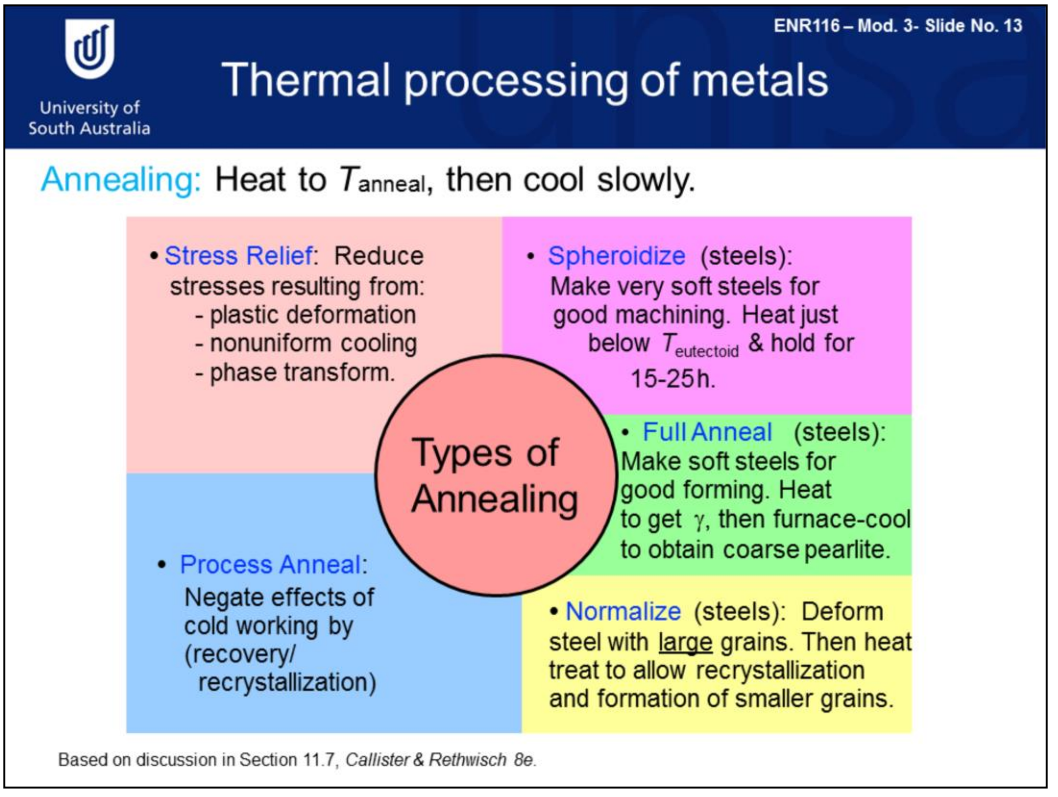
•Of the miscellaneous metal fabrication techniques two are powder metallurgy and welding.

•Powder metallurgy is applied to those metals and alloys with no or little ductility i.e. the very brittle metals. In fact a similar fabrication technique is also used for ceramics for the very same reason.

•Small particles, powder of the metal are placed in a mould and under heat and pressure the particles fuse together. This is a difficult fabrication technique to apply correctly and as such is expensive however for some metals it’s the only way.

•Welding is a highly specialised form of fabrication where very large workpieces are required. This method then assembles the piece from many smaller pieces.

•It is essentially a form of localised heat treatment and seeks to form a join by melting and fusing the metals. This naturally produces a different local microstructure to the remainder of the pieces. For this reason welding in itself is a specialised an large topic of metal fabrication.



•The heat treatment or thermal processing of metals and alloys is known as annealing.

•The process involves heating the metal or alloy, holding at an elevated temp for a period of time and cooling all in a controlled manner.

•There are many types and effects of annealing as seen on the slide here.

•Stress relief is a major reason for heat treatment. The stresses caused by the imperfections and dislocations within the microstructure can be removed or more appropriately relocated with annealing. So, for example, dislocations can move to grain boundaries.

•Spherodizing of steels again alters the microstructure. Here we create spheroids or particles of the cementite in the alpha ferrite matrix which softens the steel.

•The other types of annealing are all designed to work and modify the microstructure at an elevated temp such that the mechanical properties can be changed to better suit the application.

•Many other material types i.e. polymers and glasses also benefit from annealing for stress relief and recrystallisation.

ENR116 – Mod. 3- Slide No. 14

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Heat treatment temperature-time paths

a) Full Annealing

b) Quenching

c) Tempering (Tempered Martensite)

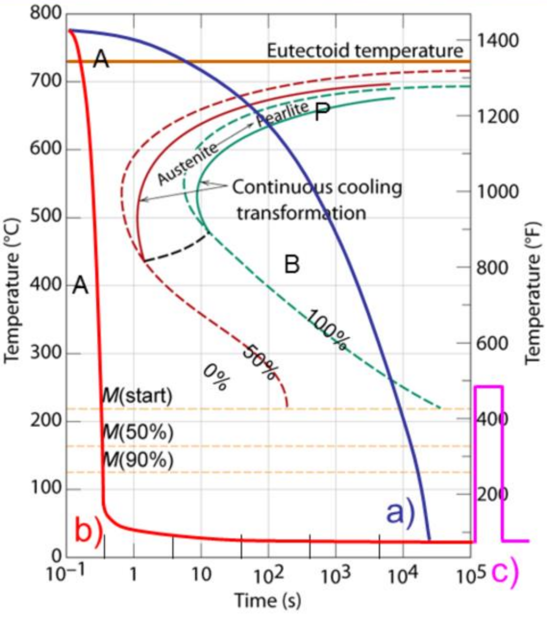
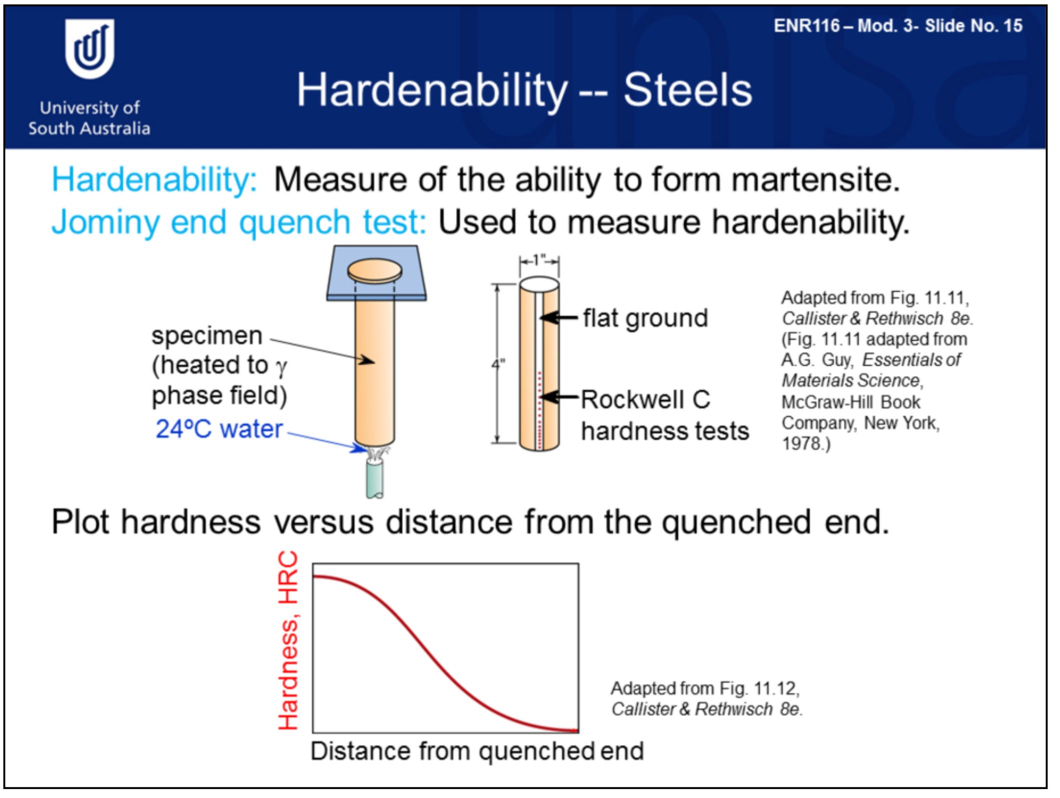


Fig. 10.25, *Callister & Rethwisch 8e.*

•We can now bring together a range of potential heat treatments and consider these with the temp time diagrams from a previous lecture summary.

•So by following the blue line we can see what effect a constant cooling process would have on the microstructure. Phase transformation from the austenite through to the pearlite and bainite.

•Alternatively we can rapidly quench and temper as seen in lines b and c. In this manner we can access the martensite region then temper that martensite to give us the final desired pearlite microstructure.

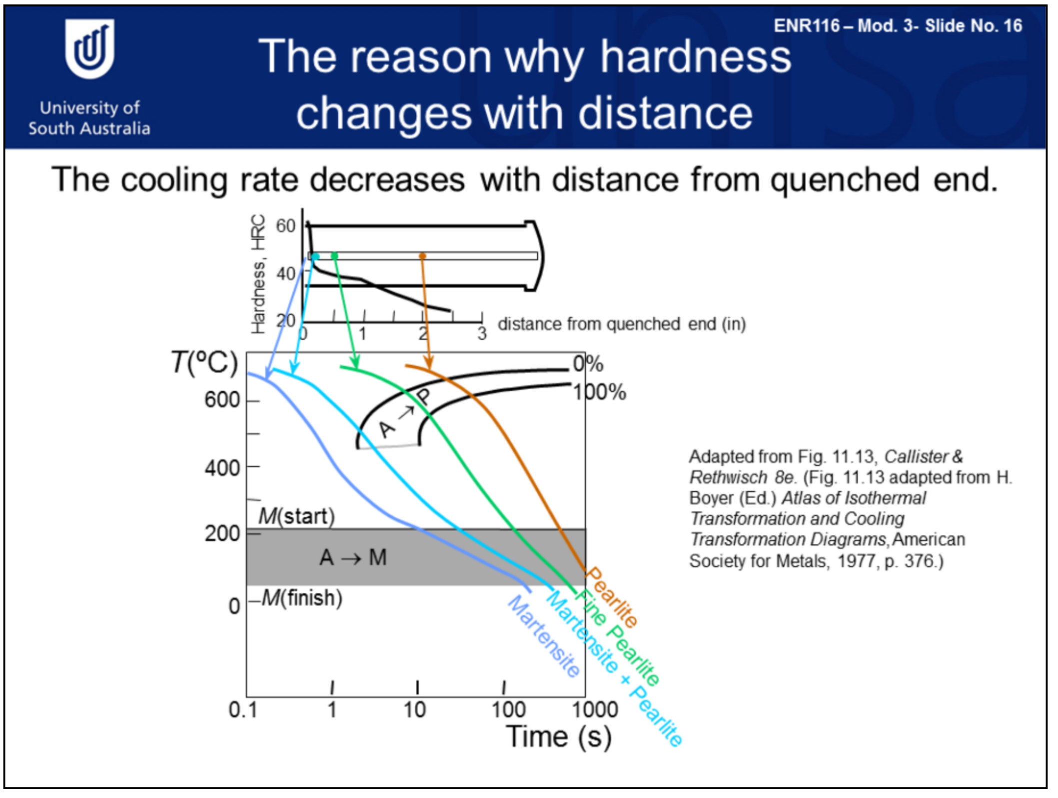


•There are however limitations in the heat treatment of metals and alloys. Especially when trying to rapidly cool, quench materials.

•We saw earlier that these transformations are subject to kinetics and temperature gradients will exist in the workpiece.

•We can determine the hardenability of a specific steel using the Jominy end quench test which is the subject of the second practical assignment.

•We heat a specimen of steel and then rapidly cool one end. The hardness of the bar is then determined along it’s length and a plot of hardness against distance gives us a hardenability curve.



•The hardenability of the bar from the Jominy end quench test is related to cooling rates.

•As the distance from the end of the bar increases the cooling rate decreases and we can transpose these measurements onto a temp-time graph.

•Close to the end of the bar we can easily quench rapidly enough to access the martensite region.

•As we move further away from the quenched end it become more and more difficult and eventually impossible so we start to form some of the other microstructures.

•It is for this reason that workpieces have limitations in terms of size and volume depending on the microstructure we wish to form.

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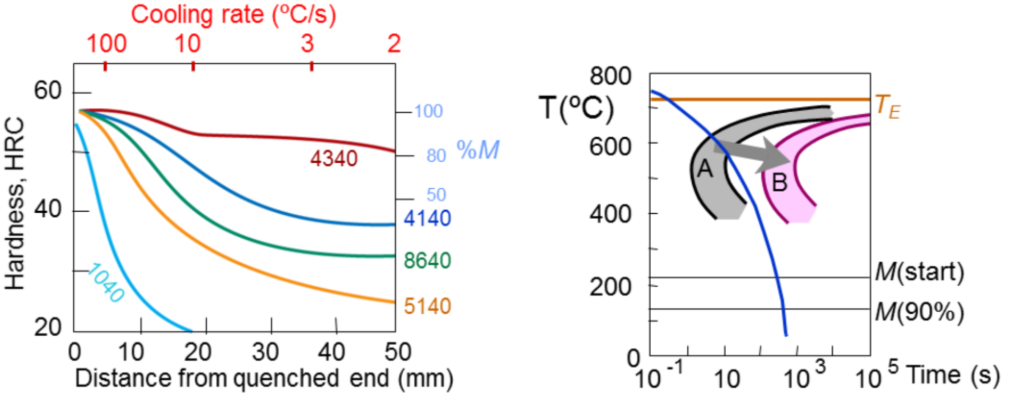
Hardenability vs. Alloy composition

Hardenability curves for five alloys each with, *C* = 0.4 wt% C.

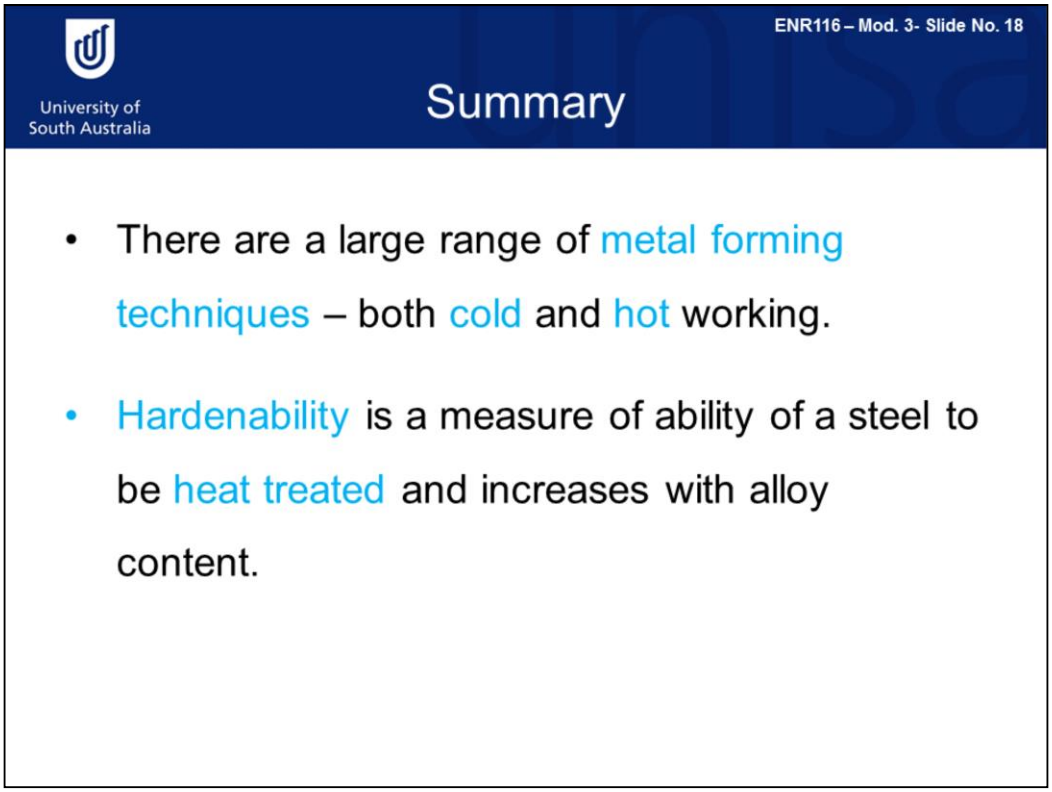


Adapted from Fig. 11.14, *Callister & Rethwisch 8e*. (Fig. 11.14 adapted from figure furnished courtesy Republic Steel Corporation.)

- "Alloy Steels" (4140, 4340, 5140, 8640) contain Ni, Cr, Mo (0.2 to 2 wt%)
- These elements shift the "nose" to longer times (from A to B).
- Martensite is easier to form

•One way to increase the workpiece size is by alloying with different metals.

•As we add the alloying elements such as nickel, chromium, molybdenum, we can modify, the temp-time curves. We delay the austenite to pearlite transformation such that we can access the martensite region with lower cooling rates.



•In summary there are a large number of different metal forming techniques that can be applied.

•The metals and alloys can be both cold and hot worked and there will have been many of these forming processes applied before the final component is ready for application.

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Thank you

If you have any questions please post these to the Engineering Materials Discussion Forum.