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Effects of heat treating on the toughness, hardness and microstructures of AISI 1060 and 4340 steels.

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Introduction

Steels can be heat treated to produce a great variety of microstructures and properties. Generally, heat treatment can make steel to have phase transformation during heating and cooling and changes its microstructure in a solid state. In general, the mechanical properties and microstructures of steels can be affected by the heat treatment. In this work, we studied the hardness, toughness and microstructures of AISI 1060 and AISI 4340 steels after five different heat treatment processes. The effects of alloy elements and heat treatment process on the mechanical properties of steels were discussed.

Specimen

Chemical compositions of steels

Element (wt.%)	C	Ni	Cr	Mo	Mn
AISI 1060	0.55-0.65	0	0	0	0.6-0.9
AISI 4340	0.38-0.43	1.65-2.0	0.7-0.9	0.2-0.3	0.6-0.8

V notched Charpy type Specimen

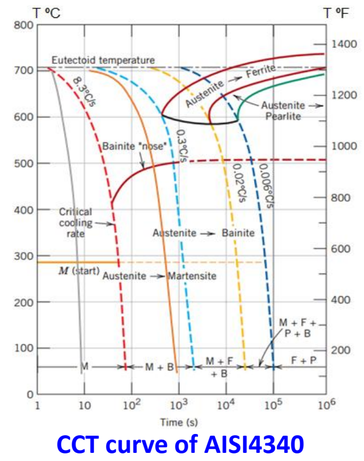
Experimental procedure

1.Heat treatment → 2.Impact test → 3. Microstructure analysis → 4. Hardness measurement

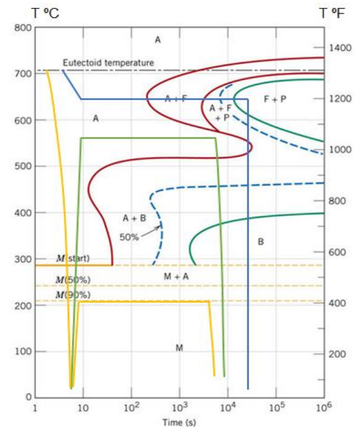
Heat treatment

Heat treatment	AISI 1060		AISI 4340	
	Temp.	Holding Time	Temp.	Holding time
Full annealing	830 ~ 650°C	830°C : 24 min 830→650: Continue cooling within 6.5 hours.	830°C ~ 650°C	830°C :24 min 650°C : 8 hr
Normalizing	830°C	24 min	870°C	24 min
Quenching	815°C	24 min	845°C	24 min
Tempering	205°C	2 hr	205°C	2 hr
	550°C	2 hr	550°C	2 hr

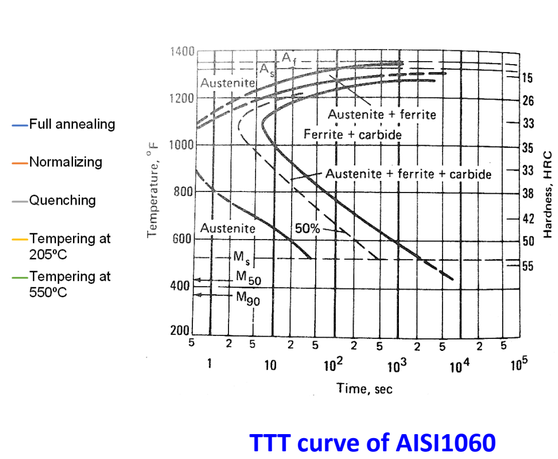
CCT



CCT curve of AISI4340

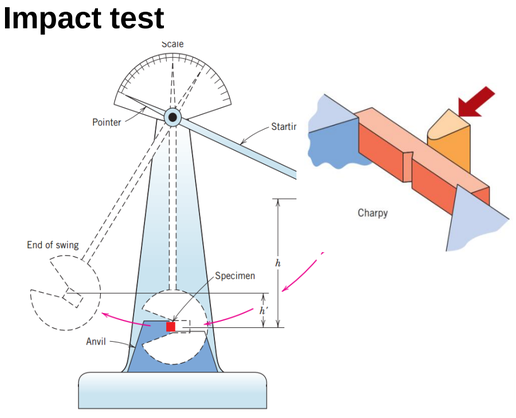


TTT curve of AISI4340

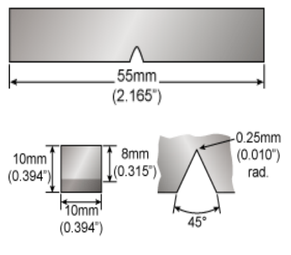


TTT curve of AISI1060

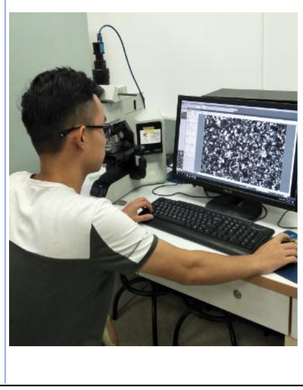
Impact test



Charpy V-notch test determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's notch toughness.

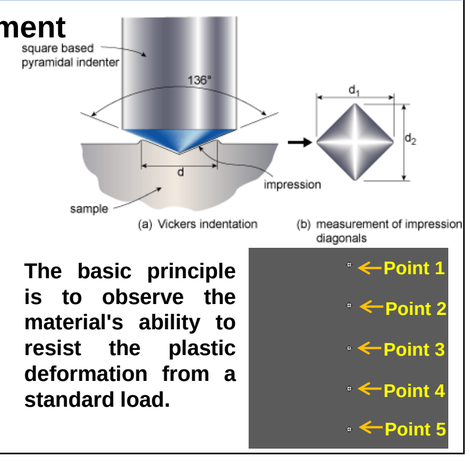


Examine the microstructure



Use optical microscope to observe microstructure of steel. The physical and mechanical properties of steel may be related to its observed microstructure.

Hardness measurement



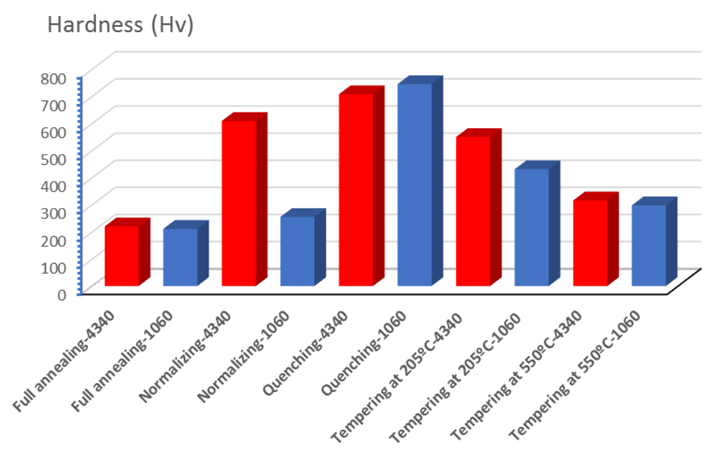
The basic principle is to observe the material's ability to resist the plastic deformation from a standard load.

Result

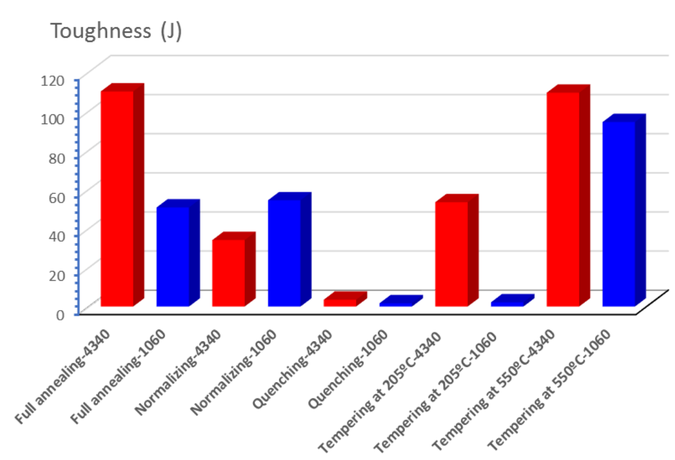
Treatment	Full annealing		Normalizing		Quenching		Tempering at 205°C		Tempering at 550°C	
Sample	AISI 4340	AISI 1060	AISI 4340	AISI 1060	AISI 4340	AISI 1060	AISI 4340	AISI 1060	AISI 4340	AISI 1060
Average hardness (Hv)	219.8	210.6	608.6	254.6	707.2	744.4	549.6	430.8	315.6	297.4
Standard deviation (Hv)	18.8	18.5	41	26.4	23.1	31.9	15.5	12.4	14.8	8.4

Treatment	Full annealing		Normalizing		Quenching		Tempering at 205°C		Tempering at 550°C	
Sample	AISI 4340	AISI 1060	AISI 4340	AISI 1060	AISI 4340	AISI 1060	AISI 4340	AISI 1060	AISI 4340	AISI 1060
Average Toughness (J)	110.0	50.7	34.0	54.3	3.5	1.7	53.3	2.2	109.3	94.3
Standard deviation (J)	9.0	3.1	0.0	1.5	0.9	0.3	11.1	0.8	7.5	30.6

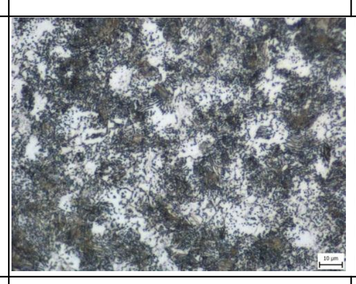
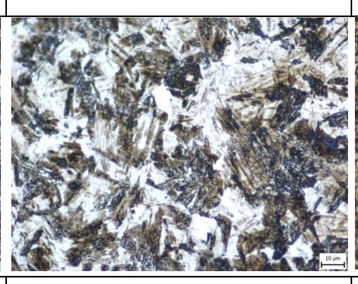
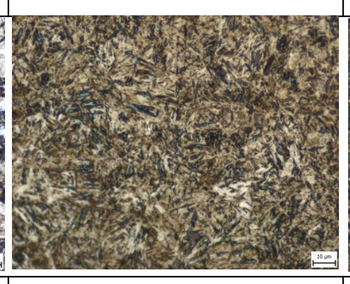
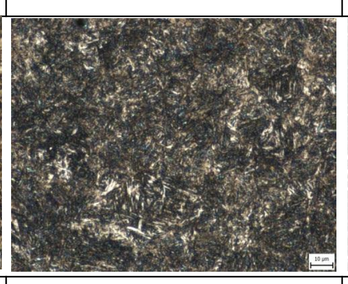
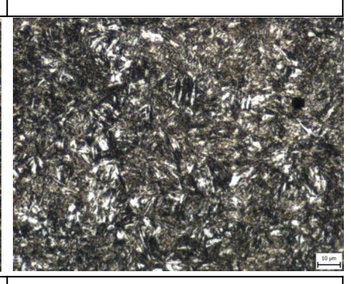
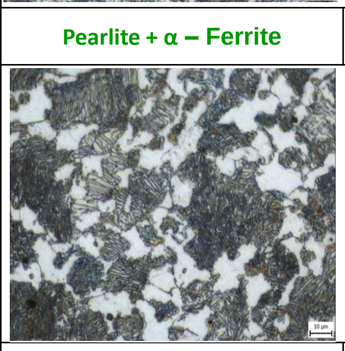
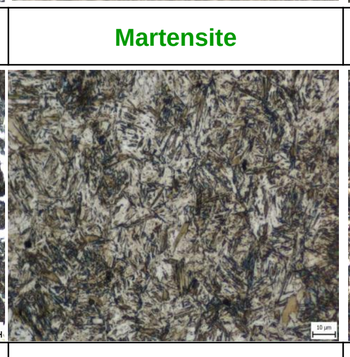
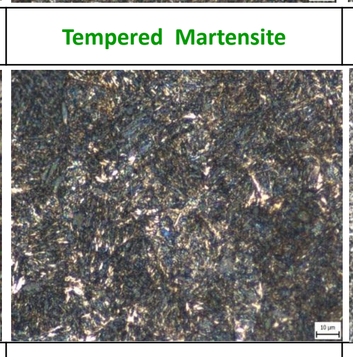
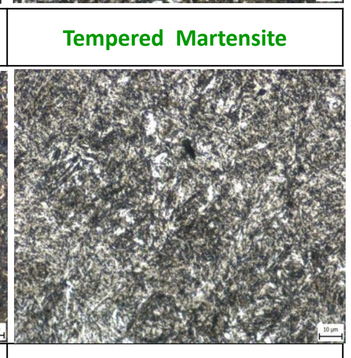
Hardness measurement



Toughness measurement



Microstructure

	Full annealing	Normalizing	Quenching	Tempering at 205°C	Tempering at 550°C
AISI 4340					
Phase	Pearlite + α – Ferrite	Bainite+α-Ferrite+ Martensite	Martensite	Tempered Martensite	Tempered Martensite
AISI 1060					
Phase	Coarse pearlite + α – Ferrite	Fine pearlite + α – Ferrite	Martensite	Tempered Martensite	Tempered Martensite

The internal oxidation defect causes the steel to absorb more energy so that the toughness increases to a higher value.

Conclusions

- ✓ The lowest hardness can be found for steels after full annealing due to the formation of soft ferrite phase.
- ✓ For AISI 1060 steel, the hardness of normalizing is higher than that of full annealing because of the formation of fine pearlite.
- ✓ Martensite phase has needle shape grains which makes the steel becomes very hard and very brittle.
- ✓ The tempering can release the stress and forms tempered martensite. The hardness of the steel after tempered at 550°C is lower but the toughness is greatly enhanced.
- ✓ For AISI 4340 steel, the Bainite structure has a very high hardness and moderate toughness.
- ✓ The combination of moderate hardness (316 Hv) and high toughness (109 J) can be found for AISI 4340 steel after tempering at 550°C due to its good hardenability by adding Cr, Ni and Mo elements.