Lab Experiment # 7

Jominy End-Quench Test

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Objective

The Jominy End-Quench Test is intended to measure the hardenability of various steel composition at different distance from site of quench. Such test should result in an understanding of how quenching process is a distance dependent procedure.

Equipment/Materials

- Rockwell hardness tester
- Specific Furnace
- Jominy Cooling System
- Various Steel Specimen as listed in the table below:

AISI No.	% C	% Cr	% Mo	% Ni	Process
1018	0.18				CF
1042	0.42				CF
1095	0.95				HR
4140	0.4	1	0.2		CF
4340	0.4	0.8	0.25	1.8	CF

Figure 1: Composition of Steel Specimen used in this lab.

Experimental Procedure

1. Place one of the samples into the furnace at 1600°F for about 1 hour
2. Remove the sample and place into the Jominy Cooling System, where the water flow rate should be adjusted where held an inch of the specimen is hitting the water stream.
3. Once Specimen has reached room temperature, carefully remove from the cooling system and remove the oxidation formed on the specimen. Specimen shall now be machined for a smooth flat surface.
4. The Rockwell machine should be set up with a 150 kg weight at c scale with a Brale indenter.
5. Readings will be taken at various distance from the quench end (labeled in Table 2).
6. Repeat the procedures for all the outlined steel specimens.

Experimental Results

Jominy Distance (in)	**St 1042**	**ST 4340**	**ST 1018**	**ST 1095**	**ST 4140**
1/16	**53**	**57**	**44**	**60**	**51**
2/16	**53**	**56**	**39**	**59**	**50**
3/16	**51**	**55**	**30**	**48**	**51**
4/16	**50**	**55**	**22**	**49**	**51**
5/16	**49**	**56**	**21**	**54**	**52**
6/16	**43**	**58**	**17**	**49**	**52**
7/16	**38**	**56**	**15**	**47**	**51**
8/16	**41**	**56**	**14**	**46**	**52**
9/16	**30**	**56**	**15**	**45**	**51**
10/16	**29**	**56**	**14**	**45**	**51**
11/16	**27**	**55**	**15**	**47**	**52**

12/16	**27**	**57**	**15**	**46**	**49**
13/16	**29**	**56**	**14**	**49**	**49**
14/16	**29**	**55**	**12**	**43**	**48**
15/16	**26**	**55**	**11**	**46**	**48**
16/16	**25**	**56**	**11**	**43**	**46**
20/16	**31**	**55**	**7**	**40**	**39**
24/16	**32**	**54**	**5**	**38**	**35**
28/16	**38**	**55**	**6**	**37**	**32**
32/16	**39**	**54**	**6**	**44**	**33**

Figure 2: Rockwell C Hardness of Steel Specimen tested at different distances from Quench End.

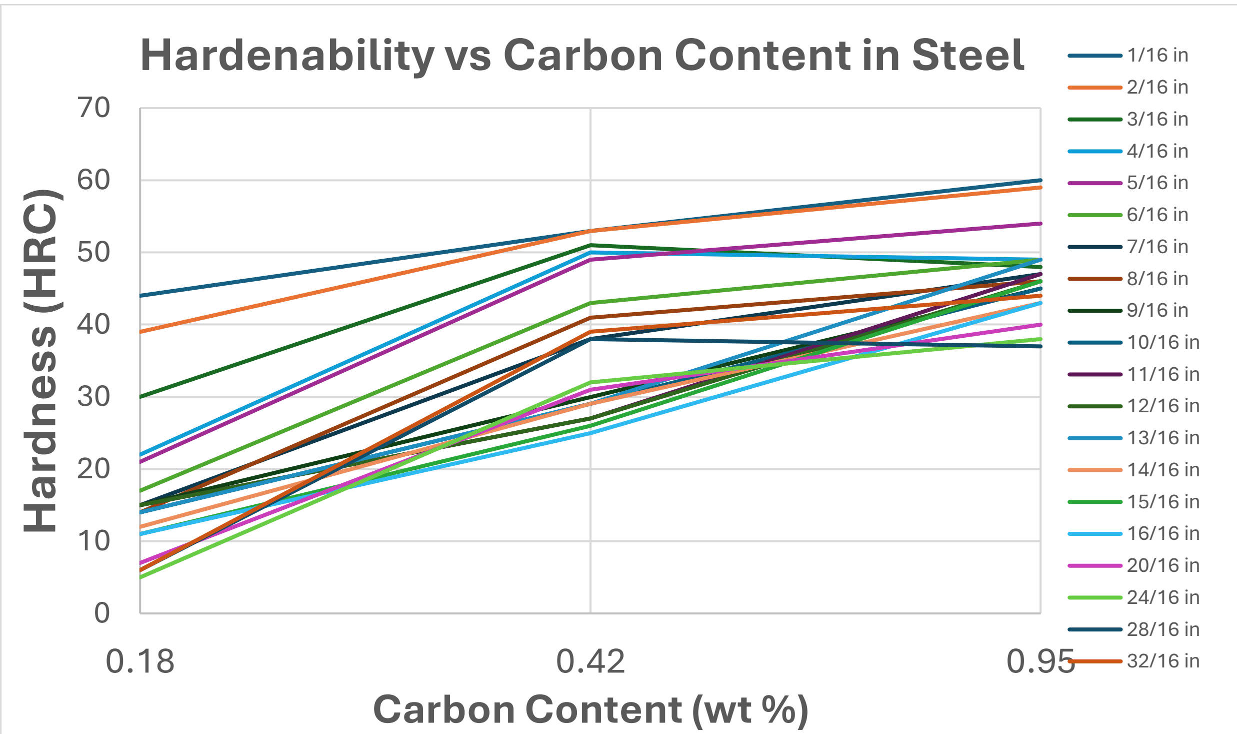


Figure 3: Hardenability of the Hardness vs the carbon content of the plain carbon steels at various distance from quench end.

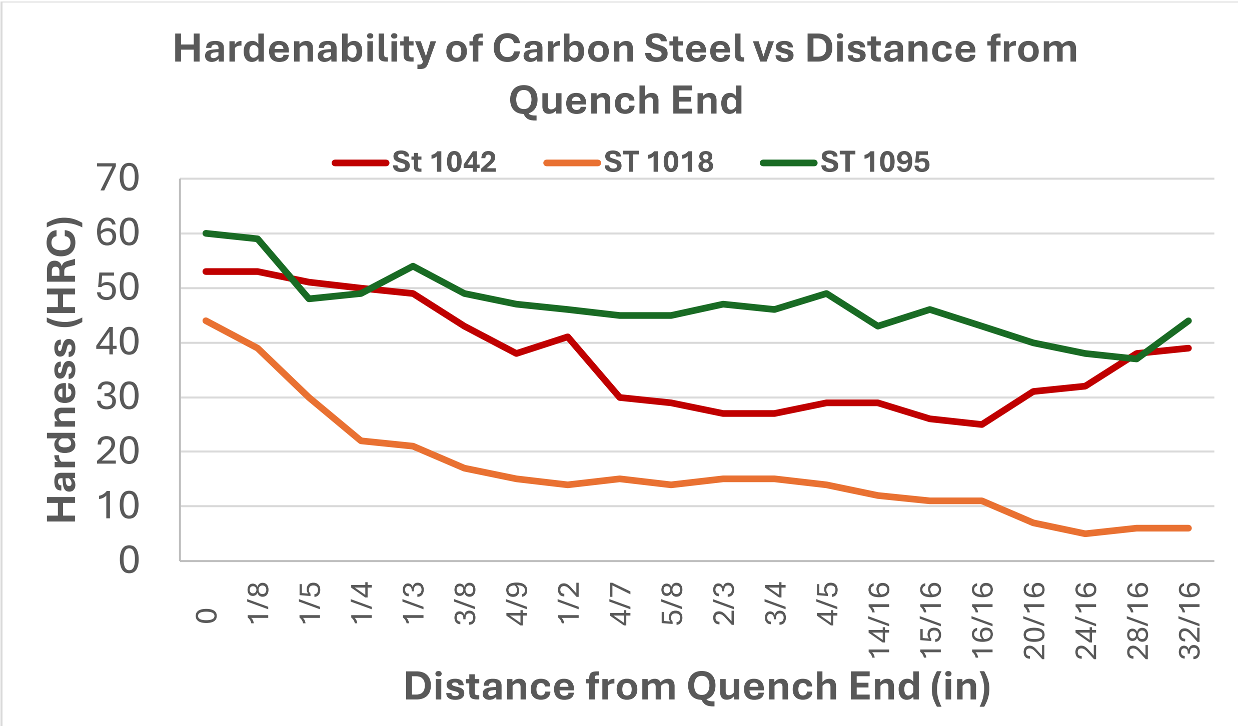


Figure 4: Hardness vs distance from the quench end of the 3 plain carbon steel specimens

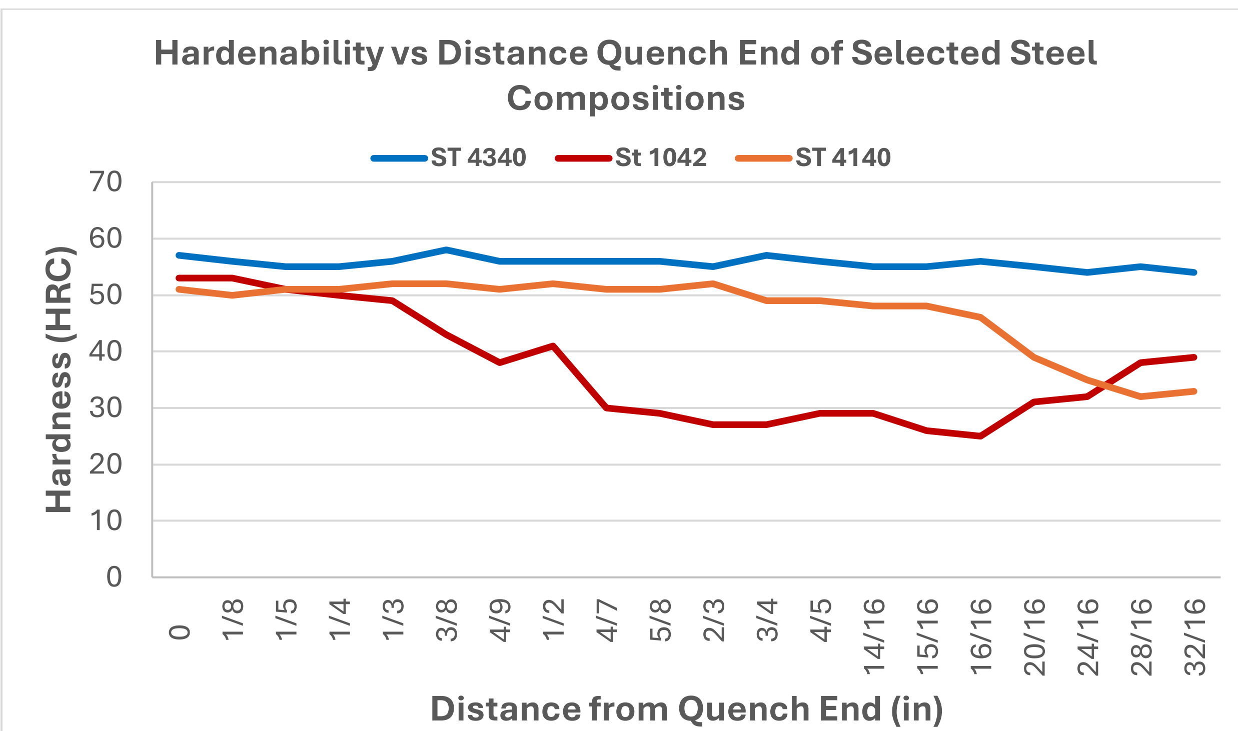


Figure 5: Hardness vs Distance from quench end of St 4340, ST 1043, and ST 4140.

Discussion of Results

Carbon content in Steel affects the overall hardness of the material. From Figures 2, all the distance from quench end reported higher hardness as the carbon content increased. Such a result can be explained by the mechanical properties of the compositions. Lower carbon steel has more iron, which is typically a more ductile and soft material as opposed to carbon, associated with traits of hardness and toughness.

From figures 2 and 3 it can be seen that the overall hardness of more steel goes down as the measurement distance from the quench end increases. The process of quenching is meant to restore hardness taken away from heat treatment by the formations of martensite. However, such process is also distance dependent and may not uniformly develop the microstructure the same throughout the specimens. For the plain carbon steels and ST 4140, this observation holds true. Such testing is meant to demonstrate the uniform behavior of quenching for specimen from the center.

Some material compositions, as seen with Steel 4340 are likely to develop uniform formation of martensite as seen in table 5. Such composition has a cooling rate high enough throughout to allow for formation of martensite over the pearlite microstructure. Martensite formation often needs to occur more rapidly, therefore materials with higher cooling rates may display more hardness throughout the quenching process.

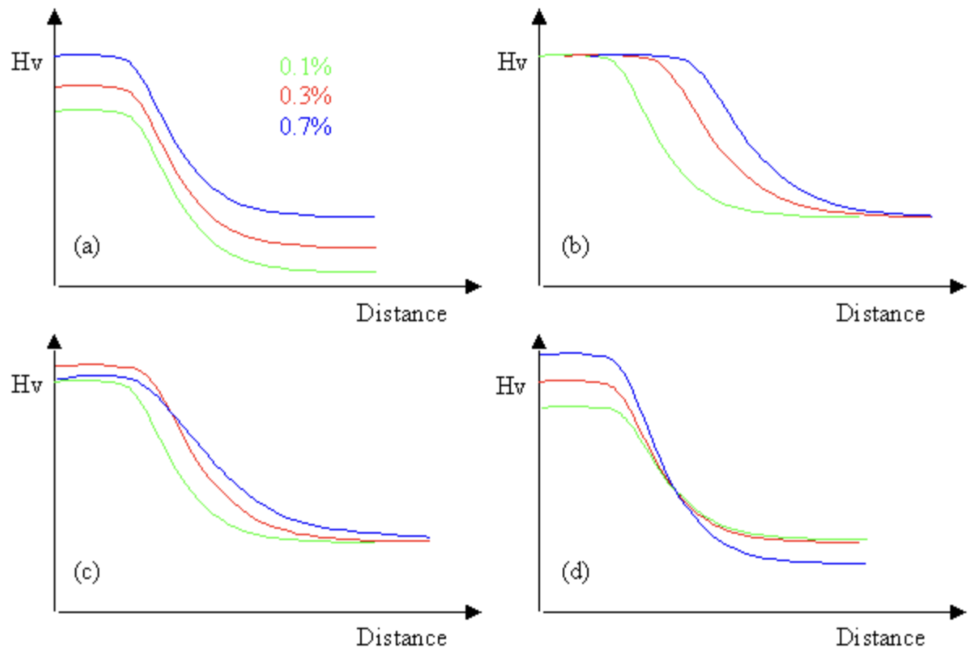
Conclusion

Hardenability for steel can change due to the composition and distance from end quench sites. As seen in this lab, certain compositions such as steel 4340 has a quicker cooling rate which allows for a even hardness distribution even over higher distance from quench site. In contrast, the different plain carbon steels all displayed a decrease in hardness further from the site of quenching. Such end quench experiment is used to observed the behavior of steels in the quenching process and testing the uniform formation of martensite.

Review Questions

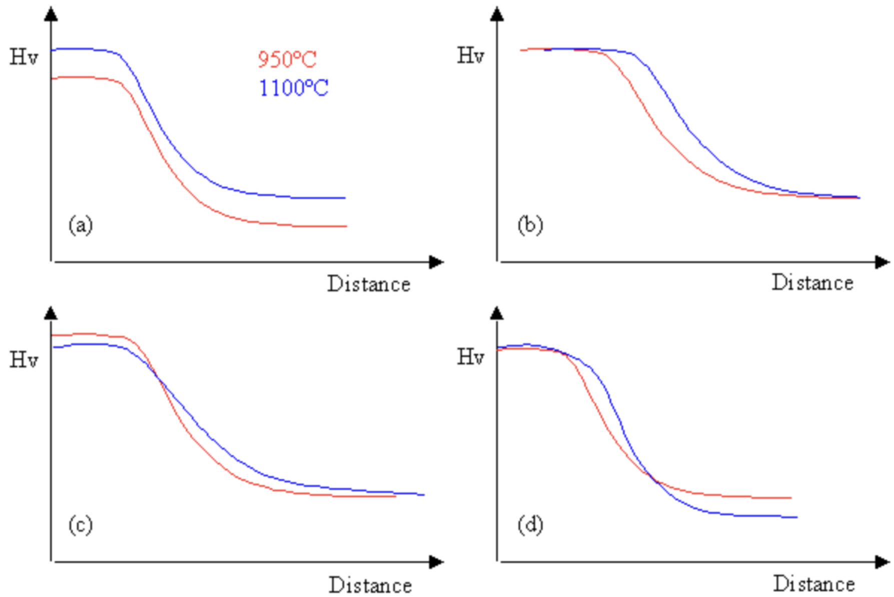
1. Online at http://www.msm.cam.ac.uk/doitpoms/tlplib/jominy/questions.php

1. Three low alloy steels, which differ only in their carbon content (0.1, 0.3 and 0.7 wt% carbon) are characterised using the Jominy end quench test. Select the plot of hardness variation along the test specimen that best describes their behaviour.



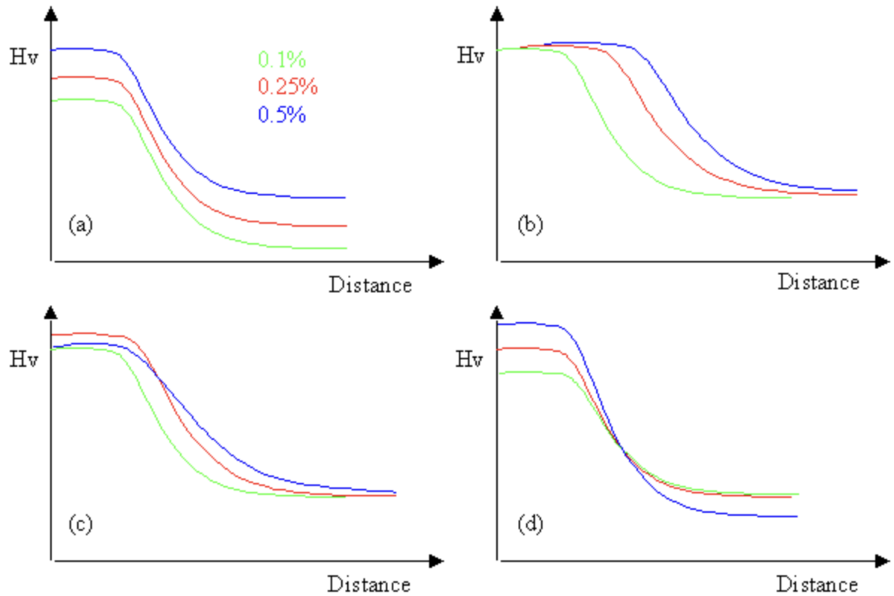
- a Plot (a)
- b Plot (b)
- c Plot (c)

2. Two specimens of a low alloy steel with 0.3wt% carbon are characterised using the Jominy end quench test. One was austenitised at 950°C, and the other was austenitised at 1100°C. Select the plot of hardness variation along the test specimen that best describes their behaviour.



- a Plot (a)
- b Plot (b)
- c Plot (c)
- d Plot (d)

3. Three medium carbon steels (0.3wt%) that differ only in their Chromium content (0.25, 0.5 and 1 wt%) are characterised using the Jominy end quench test. Select the plot of hardness variation along the test specimen that best describes their behaviour.



- a Plot (a)
- b Plot (b)

4. You have three steels. Select the most appropriate steel to achieve the necessary levels of mechanical properties, residual stress and distortion in a 1mm diameter wood-working drill.

   - a 1% C, 0.4% Si, 1% Mn, 5% Cr, 1% Mo
   - b 0.4% C, 0.4% Mn, 0.3% Si
   - c 0.5% C, 4% Cr, 6% Mo

   Answer

5. Again, you have three steels. Select the most appropriate steel to achieve the necessary levels of mechanical properties, residual stress and distortion in an injection moulding die for a mobile phone plastic case.

   - a 1% C, 0.4% Si, 1% Mn, 5% Cr, 1% Mo
   - b 0.4% C, 0.4% Mn, 0.3% Si
   - c 0.5% C, 4% Cr, 6% Mo

   Answer

6. Again, you have three steels. Select the most appropriate steel to achieve the necessary levels of mechanical properties, residual stress and distortion in a tool for high speed milling of steel components.

   - a 1% C, 0.4% Si, 1% Mn, 5% Cr, 1% Mo
   - b 0.4% C, 0.4% Mn, 0.3% Si
   - c 0.5% C, 4% Cr, 6% Mo

2. Predict the microstructure of the steel all along the bar in correlation with your

hardness measurements. What is the ideal critical diameter and can it be determined with a Jominy test?

Hardness in the bar will go down as the distance from the quench end increases. In such results, the microstructure of the bar will be closer to 100 % martensite at the surface directly being cooled during quenching with such microstructure lower as distance increase. Towards the furthest end, higher levels of pearlite would be formed. The ideal critical diameter is that in which

3. Plot hardness vs. carbon content (wt%) curve for all three plain carbon steels. What is the effect of the carbon content on hardness and hardenability? Explain explicitly.

As plotted in table 3, carbon content increases the overall hardness of the reported. Carbon is a material associated with mechanical properties such as brittleness and hardness. Iron content is a material that is often softer, thus lower carbon content will have lower hardness.

4. Plot the hardenability data (HRC vs. Distance from quenched end curve) from all of the plain carbon specimens on the same axes. Compare the hardenability, hardness of Martensite and hardness of pearlite for these three specimens. Explain how and why the carbon content for a plain carbon steel should affect each of these properties according to theory. Then examine your data to see whether it is consistent with the theory. Discuss possible reasons for any discrepancies. (References: Chapter 11: 11.8)

Hardenability of higher carbon content is seen to have a higher measured hardness (figure 4). Higher carbon content allows for more formation of martensite as the transition temperature is higher and therefore allowing for rapid transitions to martensite during quenching. The data largely displays this behavior though possible error can include the uneven cooling when placed into the cooling systems and extended time between placing the specimen into the cooling system after taking out of the furnace.

5. Plot the data from the 1042, 4140 and 4340 specimens on the same graph. Compare your results with those shown in Fig.11.14 in the textbook (p393). Discuss how the hardness values compare near the quenched ends, as well as the differences among the three hardenability curves. In explaining this data, be careful to distinguish between cooling rate (CR) and critical cooling rate (CCR).

From figures 11.14 [4], it can be seen that the critical cooling rate of the ST 4340 is different than that of the St 1042 and St 4140 due to the different hardness observed over the distance. Due to St 4340 ability to form martensite early on, it can be concluded it has a lower CCR. The cooling rate can be seen to differ by when the hardness values drop.

6. The Jominy test provides information about how completely various steels harden, both near and far from the site of rapid quenching. Full surface quenching involves immersing the austenitized part completely in a quenching medium, such as cold water. Discuss how the cross sections of fully quenched bars of 1042 and 4340 of various diameters might compare.

The Jominy Test is meant as a method to test for the hardness at the cross section of a material under a full surface quenching, therefore such results must be similar to that observed in the Jominy testing. The steel 1042 will display a decrease in hardness over distance from the surface while the steel 4340 will have similar hardness observed from distances away from the surface.

7. Both 1042 steel and 4340 steel are used commercially to make quenched round bars of about the same diameter, such as 1 in. Often, these are fully quenched. Referring to your discussion in 5, give an example of a product for which a steel like 1042 would be preferred, and one for which 4340 or a similar material would be chosen. Explain the reason for the selection of the material in each case

Steel 1042 is seen to display lower hardness by the end of the quenching process. Such material will also not have constant hardness. Moderate hardness steel may have applications where some toughness is required such as in the use of gears and shafts. Steel 4340 on the other hand displays more hardness and can be used for aerospace components, where the material will be under higher stress.

References

[1] CCNY ME 46100 Lab Report Preparation, CUNY blackboard website.
[2] CCNY ME 46100 Lab Manuals, CUNY blackboard website.
[3] CCNY ME 46100 Lab Data, CUNY blackboard website.
[4] Jr. William D. Callister_ David G. Rethwisch - Materials science and engineering _ an introduction (2018, Wiley)