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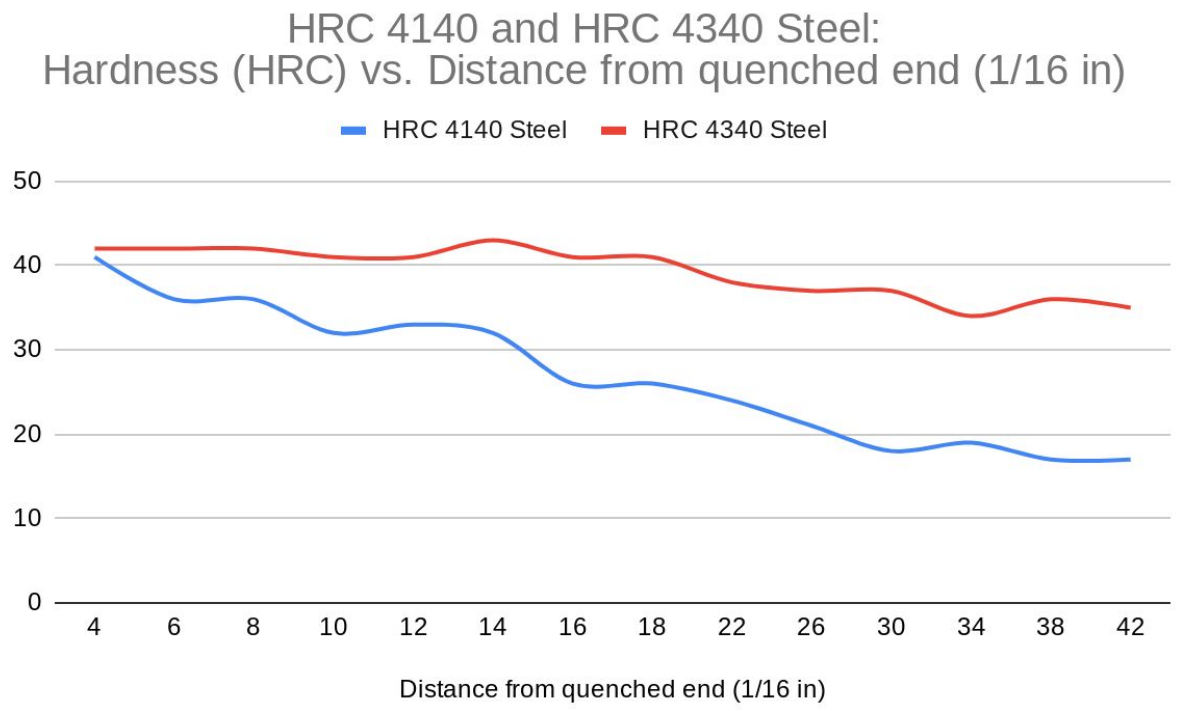
Lab 6: Hardenability Lab Report

Note: With permission from Professor Dues, data was provided by John Barger and Michael Curry.

1. Using the data recorded, plot a hardenability curve (hardness vs. distance) for the 4140 and 4340 steel Jominy bars on a single plot (see text, Fig. 7-9).

Jominy Recorded Data		
Distance from quenched end (1/16 in)	HRC 4140 Steel	HRC 4340 Steel
4	41	42
6	36	42
8	36	42
10	32	41
12	33	41
14	32	43
16	26	41
18	26	41
22	24	38
26	21	37
30	18	37
34	19	34
38	17	36
42	17	35



2. Discuss the difference between hardness and hardenability. What affects each (be specific, i.e. does it increase hardness/hardenability or decrease it; if composition affects one, what alloying elements affect it)?

Hardness is a "relative value" which "compare(s) the metal tested against a scale, and the value obtained varies with the method used." [Dalton, p. 383] Of note the hardness conversion tables are based on "specific metals". [Dalton, p. 393] Also "[o]ther metals with different elastic and/or strain hardening characteristics might respond differently to the various indenters and loads." [Dalton, p. 393]

Hardenability is the "property of steel that enables it to form martensite at slower cooling or quenching rates; a TTT (Time Temperature Transformation) that is moved to the right or a flatter Jominy curve indicates hardenability." [Dalton, p. 443] Hardenability, is the ability of a metal or alloy to "achieve the hard transformation product of γ-austenite (martensite) at slower cooling rates. Since the hardness depends on the carbon content, hardenability is not the same as hardness but is the ability to harden, the ability to become martensite". [Dalton, pp. 158-159] Of note is that for "normalized and slow-cooled plain carbon and medium-alloy steels, it has been found empirically that their tensile strengths will be approximately 500 times their Brinell hardness." [Dalton, p. 393]

For the Jominy test, two assumptions are made: "the composition of the specimen is uniform; thus the cooling rate is the only variable influencing hardness" and that the "heat conductivity of steel is essentially a constant, regardless of composition." [Dalton, p. 412] Using the Jominy test allows one steel to be compared to another so that the test specimens "can be used to compare the hardenability of steels at different compositions". [Dalton, p. 412]

The "typical purpose of using alloying elements to form solid solutions with austenite is to improve [the] hardenability of the steel." [Dalton, p. 182] As well as the "effect of alloying elements on hardenability is similar in some ways to the effects of grain boundaries. The dissolved foreign atoms are thought to migrate to grain boundaries, where they seem to act as pins, preventing the boundaries from shifting; the recrystallization or transformation of the austenite is thus impeded." [Dalton, p. 159]

Composition does affect hardness and hardenability in the following ways based upon which component element we are referring to:

Component Elements Properties	Usage	HRC 4140 Steel	HRC 4340
Carbon, C	It increases hardness and strength, and improves hardenability. It increases brittleness, and reduces weldability because of its tendency to form martensite. [Fabricator]	0.38 - 0.43 %	0.38 - 043 %
Chromium, Cr	Hardenability, solid solution strengthening, corrosion resistance. [Dalton, pp. 182-184]	0.80 - 1.1 %	0.70 - 0.90 %
Iron, Fe	NA	96.785 - 97.77 %	95-175 - 96.27 %
Manganese, Mn	Deoxidizer and desulfurizer. [Dalton, pp. 182-184]	0.75 - 1.0 %	0.65 - 0.85 %

Molybdenum, Mo	Hardenability, carbide former, "helps to prevent growth of [the] austenite grain size and promote fine tuned steels". Raises steel hardness, and "the tempering temperature to achieve the same amount of softening". [Dalton, pp. 182-184]	0.15 - 0.25 %	0.20 - 0.30 %
Nickel, NI	"Nickel has 100% solubility with austenite, improves hardenability, and doesn't form carbides. Nickel doesn't have 100% solubility with ferrite, since the two metals have different lattices, but it does have a large partial solubility, which improves strength and toughness at room temperature." [Dalton, pp. 182-184]	0.0 %	1.65 - 2.0 %
Phosphorous, P	"prevents the sticking of light-gauge sheets when it is used as an alloy in steel. It strengthens low carbon steel to a degree, increases resistance to corrosion and improves machinability in free-cutting steels." [Leonghuat]	<= 0.035 %	<= 0.025%

Silicon, Si	"tends to graphitize carbon so it doesn't form carbides" contributes solid-solution strengthening when dissolved in ferrite and improves strength and toughness, "reduces distortion caused by the austenite-to-martensite volume change". [Dalton, pp. 182-184]	0.15 - 0.30 %	0.15 - 0.30 %
Sulfur, S	Improves machinability. [Dalton, pp. 182-184]	<= 0.040 %	<= 0.020 %

[MatWeb, 4140] [MatWeb, 4340] [Dalton, pp. 182-184] [Fabricator] [Leonghuat]

3. Using the single hardenability curve for the 4140 and 4340 steels compare and contrast the hardenability results and explain the difference in the two alloys that lead to these results.

"The Jominy end-quench test is a standardized way to achieve a range of cooling rates and measure their effect on hardness." [Dalton, p. 424] "The Jominy test standardizes the quenchant, the agitation of the quenchant, the temperature of the quenchant, and the surface-to-volume ratio of the specimen."

The Jominy test creates a gradient hardness, and the quenched end will have a higher hardness than the normalized end. From a practical standpoint, knowing how a particular metal alloy will quench allows for an engineer to select steels that meet hardness specifications. [Dalton, p. 422]

The primary driving elements that affect hardness and hardenability for 4140 Steel is Chromium and Molybdenum, and for 4340 Steel Chromium, Molybdenum, and Nickel. The Jominy curve from the data collected indicates that the 4340 steel which has a flatter Jominy curve has a higher hardenability.

Works Cited

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