Metallurgy of Steel for Bladesmiths & Others who Heat Treat and Forge Steel

John D. Verhoeven
Emeritus Professor
Iowa State University

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Preface

For the past 15 years or so I have been working with practicing bladesmiths on problems related to forging and heat treating steel blades. It has become apparent to me in that time that there is a need for a book that explains the metallurgy of steel for people who heat treat and forge steels and have had no formal metallurgical education. This book is an effort to provide such a treatment. I have discovered that bladesmiths are generally very quick to catch on to the ideas of metallurgy and consequently an attempt was made to set the level of detail presented here for the needs of those wanting a fairly complete understanding of the subject.

Most chapters in the book contain a summary at the end. These summaries provide a short review of the contents of each chapter. It may be useful to read these summaries before and perhaps after reading the chapter contents.

The Materials Information Society, ASM International, has published a book that contains a wealth of information on available steels and is extremely useful to those who work and heat treat steel: Heat Treater's Guide, Practices and Procedures for Irons and Stteels, 2nd Edition, (1995), Materials Park, OH 44073. A major goal of this book is to provide the necessary background which will permit a practicing metal worker to understand how to use the information in the ASM book, as well as other handbooks published by ASM International.

I would like to acknowledge the help of two bladesmiths who have contributed to this book in several ways, Alfred Pendray and Howard Clark. Both men have helped me understand the level of work being done by U.S. bladesmiths and they have also contributed to some of the experiments utilized in this book. They are also responsible for the production of this book because of their encouragement to write it. In addition I would like to acknowledge many useful discussions with William Dauksch and my colleague, Prof. Brian Gleeson, who made many useful suggestions on the stainless steel chapter.

I am particularly indebted to Iowa State University and their Materials Science and Engineering Department for providing me with the opportunity to teach metallurgical engineering students about steel for over two decades, as well as to the Ames Laboratory, DOE, that supported most of my research activity. Many of the pictures and methods of presentation in this book result from my experience teaching students and doing research at Iowa State University.

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B Appendix B - Stainless Steels for Knife-makers

Chapter 13 discussed two specific steels that are used for making knives of stainless steel, Sandvik 12C27 and Uddeholm AEB-L. There are several other stainless steels often used by knife-makers and Table B-1 presents most of the popular types. These steels often contain the addition of Mo. In addition to enhancing passivity, as mentioned in Chap. 13, Mo also improves toughness in the tempered condition.

Table B-1 Stainless steels often used for knives

Steel	Mft	%C	%Cr	%Si	%Mn	%Mo	Other
440A	AISI Steel	0.7	17	1	1	0.75	-
440B	AISI Steel	0.85	17	1	1	0.75	-
440C	AISI Steel	1.1	17	1	1	0.75	-
12C27	Sandvik	0.6	13.5	0.4	0.4	-	-
AEB-L	Uddeholm	0.65	12.8	0.4	0.65	-	-
DD400	Minebea	0.61	12.9	0.32	0.67	-	-
425 M	Crucible	0.54	14.2	0.8	0.5	0.8	-
154-CM	Crucible	1.05`	14	0.3	0.5	4	-
ATS-55	Hitachi	1	14	0.4	0.5	0.6	0.4Co,0.2Cu
ATS-34	Hitachi	1.05	14	0.35	0.4	4	-
AUS-6		0.6	13.8	1	1	-	0.13V,0.49Ni
AUS-8		0.73	13.81	0.5	0.5	0.2	0.13V,0.49Ni
AUS-10		1.03	13.8	1	0.5	0.2	0.13V,0.49Ni

In the discussion of AISI 440C in Chapter 13 the 1100 Fe-Cr-C ternary phase diagram was used to illustrate the expected composition of the austenite prior to quenching. To simplify the presentation the addition of the 0.75% Mo in this steel was ignored by plotting the composition on the 1100 ^{o}C Fe-Cr-C ternary phase diagram, Fig. 13.11. Because Mo is a strong carbide forming element one would expect that the 0.75% Mo addition would make small changes to the pure Fe-Cr-C phase diagram. The diagram of Fig. 13.11 was produced by combining experimental measurements with theoretical thermodynamic calculations by a group of Swedish researchers headed by M. Hillert [13.8]. This work led to the development of a sophisticated computer software program called ThermoCalc. At the request of the author, Dr. A. Kajinic at Crucible Research in Pittsburgh PA, has used this program to calculate several Fe-Cr-C isothermal diagrams with a constant amount of Mo added. Figure B1 presents the isothermal Fe-0.8Mo-Cr-C diagram. This diagram matches the Mo level in 425M and provides a good approximation to the 0.75% Mo of the AISI 440 series of stainless steels.

Figure B1 presents the isothermal sections at both 1100 ^{o}C (the solid lines) and at 1000 ^{o}C (the dashed lines). Comparing this diagram to that of the non Mo diagrams of Fig. 13.13, one sees that the carbon saturation line at 1000 ^{o}C is shifted just slightly to lower %C values. Notice that a larger change has occurred in the position of the $\gamma + K_1 + K_2$ region (shaded regions) that lies between the $\gamma + K_1$ and $\gamma + K_2$ regions. This is illustrated well by looking at the position of the overall composition of 440C alloy located at the solid dots on the two diagrams, Figs. 13.13 versus Fig. B1. (The open circle labeled 440C gives the austenite composition at 1100 C.) The Mo addition shifts the $\gamma + K_1 + K_2$ region down and to the right on these diagrams, which favors formation of the K_1 carbide over the K_2 carbide for a given alloy composition. This result might be expected to reduce wear resistance (as K_2 is the harder carbide, see Table 13.9) if the non-Mo steels did contain mostly K_2 carbides as predicted by Fig. 13.11. However, experiments [13.12] indicate non-Mo steels have mainly K_1 carbides, so this effect is unlikely. But the Mo addition should produce some improvement in the corrosion resistance at the same level of %Cr. Calculations [B1] predict that the austenite formed at 1100 °C in 440C should contain around 0.73%Mo in addition to 12.2 %Cr.

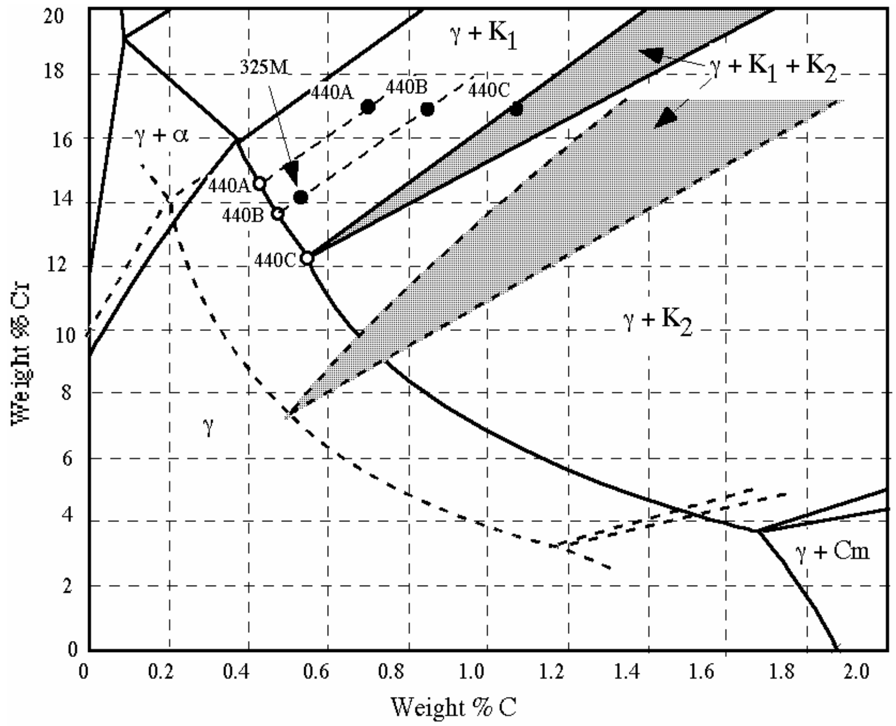

Figure B1 Isothermal sections of the Fe-C-Cr-0.8%Mo alloy system. Solide lines, 1100 °C and dashed lines at 1000 °C. ThermoCalc diagram provided by A. Kajinic [B1].

The alloy 325M is shown on Fig. B1 and it is seen to fall essentially on the tie line for AISI 440B (dashed line connecting closed and open circles labeled 440B). However its overall composition lies much closer to the carbon saturation line so that one would expect this alloy to be similar to 440B except the carbides should be present in a smaller volume fraction and the fraction of primary carbides should be negligible. The ThermoCalc predictions for the 1100 °C austenite of 325M are 13.5%Cr, 0.475%C and 0.77%Mo [B1]. Hence, one would expect this alloy to be not quite as hard as the AEB-L alloy discussed at length in Chapter 13 because of the slightly lower %C, but a bit better in corrosion resistance due to the Mo in the austenite.

The alloys ATS 34 from Hitachi and 154CM from Crucible are essentially the same alloy with the relatively high Mo addition of 4 %. The ThermoCalc prediction of the 1100 °C isotherm of the Fe-C-Cr-4 Mo system [B1] is presented in Fig. B2. At 1100 °C the isothermal section of Fig. B2 predicts that the alloy will consist of austenite plus the K_1 carbide. Additional calculations find that the composition of the austenite will be 10.6% Cr, 3.4% Mo, 0.58%C. Because the overall composition of 154CM lies off of the carbon saturation line about the same amount as 440C it is expected that the volume fraction carbides will be similar. The similar overall %C and total %Cr + %Mo in these two steels will probably result in the same problem of formation of

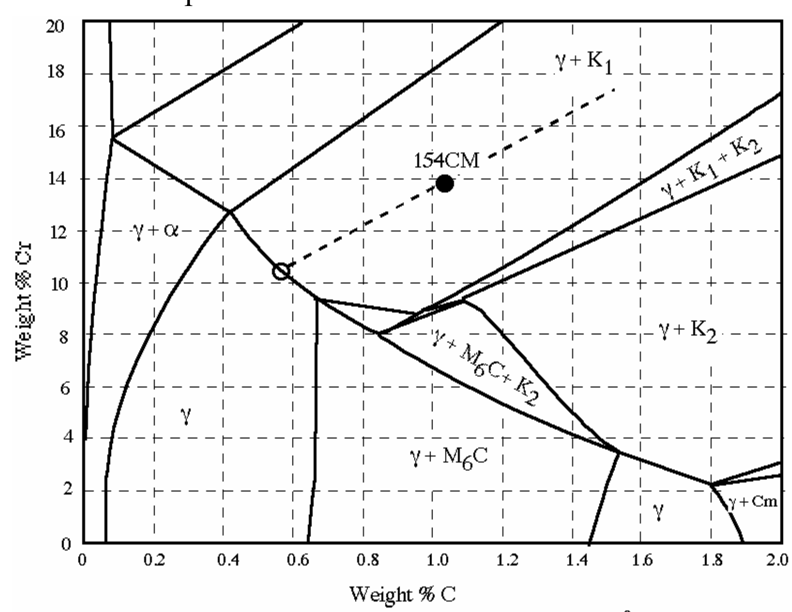

Figure B2 Isothermal section of the Fe-C-Cr-4.0%Mo alloy system at 1100 °C [B1].

large primary carbides in the solidification process.

Research on 154CM at Crucible [B1] has found that the %Cr in the austenite produced at 1065 ^oC (1949 ^oF) is approximately 10%. This result agrees well with the predicted ThermoCalc value of 10.6% at 1100 ^oC, because one would expect a value slightly less than 10.6 at the lower austenitizing temperature of 1065 ^oC. The fact that the Cr level lies below the 12% Cr value generally desired for good passivity might indicate that this steel would have poor corrosion resistance. However, the 3.4 % Mo present in the austenite should compensate for this reduction. Experiments at Crucible [B1] have confirmed this to be pretty much the case.

From this discussion it appears that the two steels discussed in Chapter 13, Uddeholm AEB-L and Sandvik 12C27, along with the similar steels of Table B1, (DD400 and AUS6) provide the best combination of properties desired in a knife blade:

(1) An as-quenched hardness in the 63 to 64 R_c range which should provide high wear resistance.
(2) An adequate level of Cr in the austenite formed prior to quenching to provide good corrosion resistance, a bit above the minimum 12 %Cr.
(3) The presence of fine arrays of the $K_1 + K_2$ chromium carbides to enhance wear resistance plus the absence of the larger primary chrome carbides that promote pull-out at sharpened edges.

Sandvik produces a series of stainless steels having compositions close to the value of the 12C27 that was considered in Chapter 13. Table B-2 presents a comparison of these steels to that of the Uddeholm AEB-L that was studied in Chapter 13. The overall compositions shown in the table were plotted on Fig. 13.11 and the predicted values of %C and %Cr in austenite at 1100 ^oC are shown in the 4th and 5th columns of the table. The volume fraction carbide in the 1000 ^oC austenite can be determined by measurement of the distance of the overall composition from the carbon saturation line. The fraction carbide in the Uddeholm AEB-L, which may be estimated from Fig. 13.17, was taken as a standard and the final column of the table presents the factor telling you fraction carbide relative to this standard. For example, the high carbon in Sandvik 19C27 produces 5.6 times more carbides at 1000^oC than found in AEB-L. This steel will produce the highest hardness in the Sandvik series, but the carbides might be larger than desired on the cutting edge due to formation of primary carbides resulting from the increased C level. And the corrosion resistance will be the poorest due to a %Cr of only 11.3%. As shown in Chapter 13 the as-quenched hardness, % retained austenite and volume fraction carbides in AEB-L is very sensitive to heat treat temperature, time and quench rate. Because the compositions of the Sandvik 12C27 and 13C26 are so similar to AEB-L it seems likely that the properties of these three steels may be more sensitive to the austenitization heat treatment than to choice of composition, unless precise heat treat conditions are utilized. The 12C27M of the Sandvik series should have the best corrosion resistance due to the highest %Cr in the austenite, but the lowered %C will produce the lowest as-quenched hardness.

Table B-2 Additional stainless steels available from Sandvik

Steel	Overall		In Austenite at 1000 ^oC		Relative volume fraction carbides (Is multiple of amount in AEB-L)
	%C	%Cr	%C	%Cr	
Ud. AEB-L	0.65	12.8	0.59	12.3	1.0 (Standard value)
Sand. 12C27M	0.52	14.5	0.52	14.5	no carbides at 1000 ^oC
Sand. 12C27	0.60	13.5	0.56	13.2	0.7
Sand. 13C26	0.65	13	0.58	12.5	1.1
Sand. 19C27	0.95	13.5	0.60	11.3	5.6

As seen in Table B-1, the Minebea steel, DD400 has a very similar composition to the Uddeholm and Sandvik steels of Table 13.7. A fairly recent paper [B.2] has compared this steel to 440C for use in bearings hardened to the HRC = 61 to 64 range. The DD400 bearings are reported to have longer bearing life, reduced noise and vibration levels. Micrographs are presented to show large primary carbides present in 440C and their absence in DD400. The improved bearing properties are attributed to the absence of the primary carbides. As explained on p 162, primary carbides are produced by formation from the interdendritic liquid during solidification. Increased levels of %C will lead to primary carbide formation due to the combination of high Cr content and non-equilibrium freezing in these stainless steels. The absence of primary carbides in the DD400 steel and the AEB-L experiments of page 139 indicate that dropping the %C level from around 1% in 440C to around 0.6% in steels containing around 13 %Cr is sufficient to reduce primary carbide formation to negligible levels during solidification.

References

B1 A. Kajinic, personal communication, Crucible Research, Pittsburgh, PA (2002).

B2 J. Rideout, Bearing steel bests type 440C, Advanced Mat. and Proc. p39, Dec. (1992).