ATLAS OF JOMINY CURVES FOR VANADIUM STEELS

The increasing competitiveness of alternative materials together with the increases in cost of fuel and labour used in heat treating steels has, in recent years, caused steel makers and steel users to re-examine the use of alloys in many types of steel particularly those used in the fully heat treated condition with the object of minimising the total cost of alloys and hence keeping steel costs to a minimum.

In some cases it has been possible to replace fully heat treated steels by "as forged" steels but where this is not feasible the total alloy contents have been reduced. A number of companies attempt to select the most economic steel composition to meet specific hardenability requirements and property specifications on the basis of alloy costs and hardenability data in the form of Di values. Some companies have, in fact, developed computer programmes for determining the optimum composition for minimum cost on the basis of this data. While Di values, which are derived from Jominy distance for 50% martensite in the microstructure, can be used for comparing steels of similar composition in which the microstructure consists of martensite and ferrite – pearlite, it is dangerous to use them for comparing steels of different alloy types because these may contain other microstructure constituents which can influence the hardness; the steels may also have different coefficients for thermal diffusivities which can effect the microstructure. The only satisfactory method of comparing the practical hardenabilities of steels of different alloy types is, in fact, to use Jominy hardness curves.

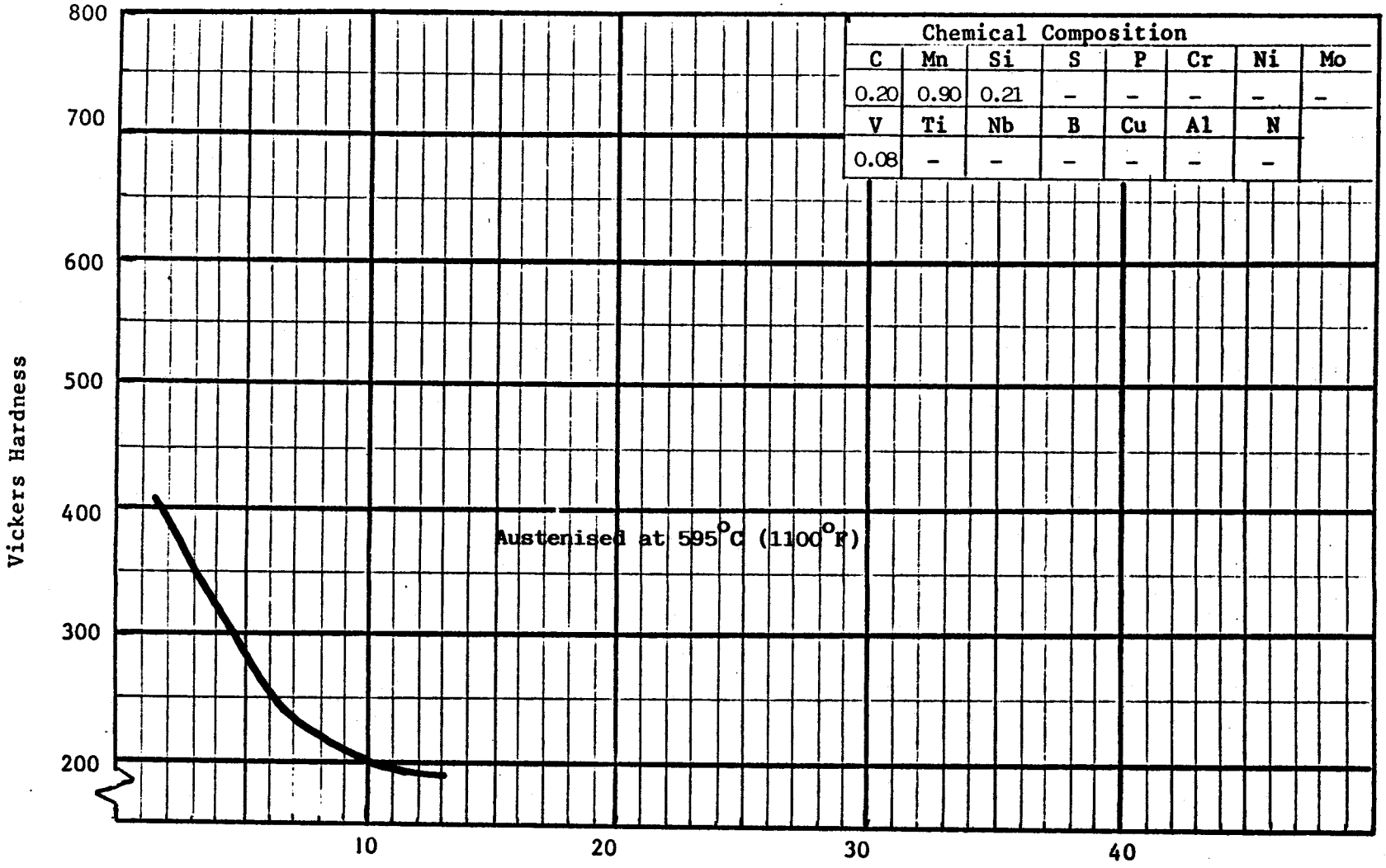
This Atlas has therefore been prepared to assist steel makers and steel users in determining the most effective use of vanadium, alone or in combination with other hardenability elements in alloy steels, particularly those used in the fully heat treated condition.

Some of the curves have been taken from published literature but most of them have not been published previously. They have, in fact, been produced in the course of projects on the possible substitution of vanadium for molybdenum in fully heat treated steels. These have been supplied by The Swedish Institute for Metals Research arising from a project undertaken for VANITEC, The Foote Mineral Company in the U.S.A. and The Sheffield University Materials Advisory Centre working with Highveld Steel and Vanadium Corporation. VANITEC wishes to acknowledge the co-operation of these organisations and companies and to thank them for permission to publish the data.

Particular attention is drawn to the high hardenability which is reported by all three laboratories for steels containing additions of vanadium together with molybdenum and titanium and in vanadium molybdenum steels when melted in vacuum. The mechanism by which these very high hardenabilities are achieved has not been established but it will be seen that the hardenabilities of these steels are of the order of those achieved in Nickel Chromium and Nickel Chromium Molybdenum steels to which the vanadium steels become competitors.

Arthur M. Sage
Chairman

Steel 1

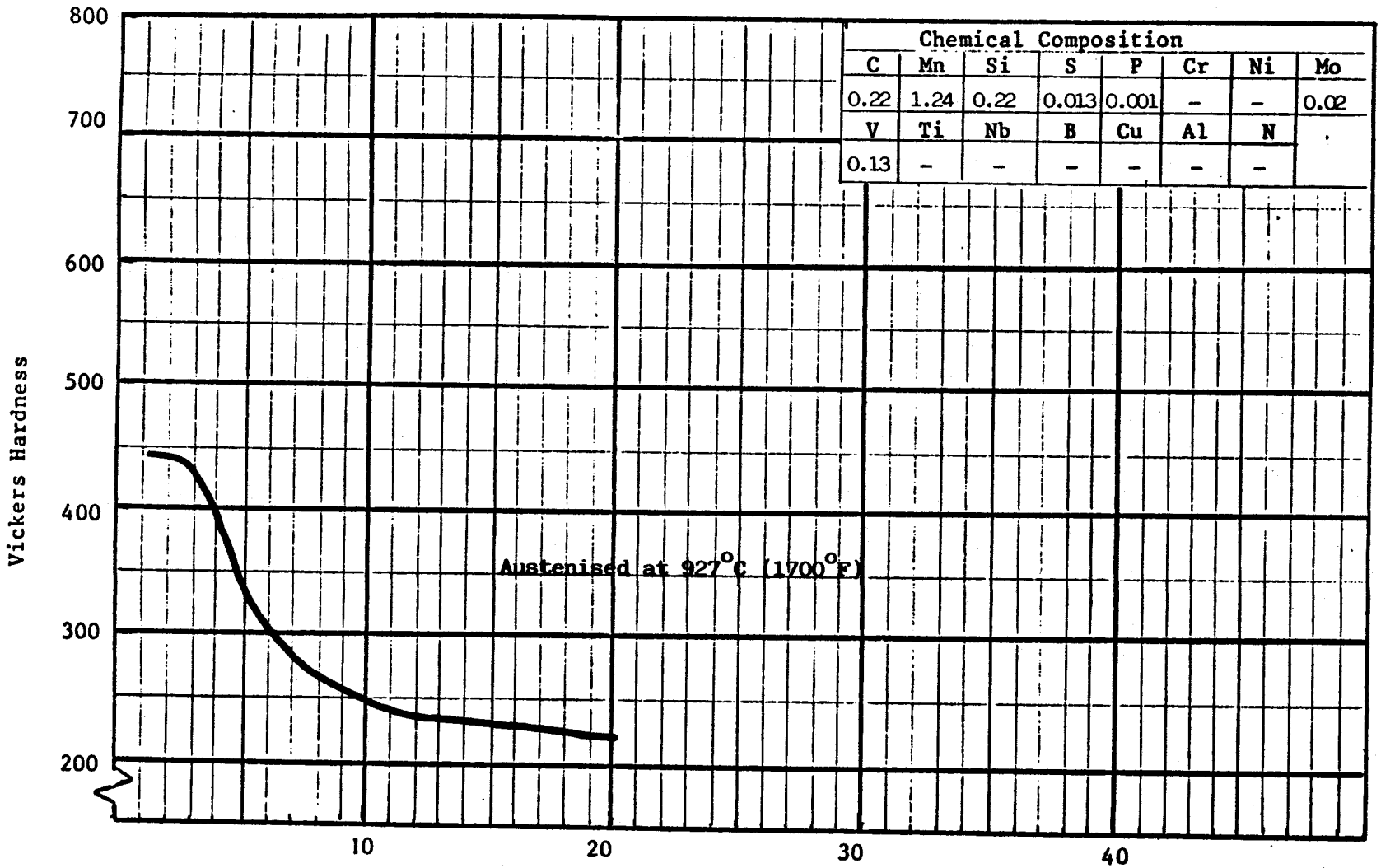


Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.20	0.90	0.21	-	-	-	-	-
V	Ti	Nb	B	Cu	Al	N	
0.08	-	-	-	-	-	-	

Source: R. D. Manning et al, in "Symposium on Transformation and Hardenability in Steels", Climax Molybdenum Co., 1967, pp. 169-177

Van ref: 97

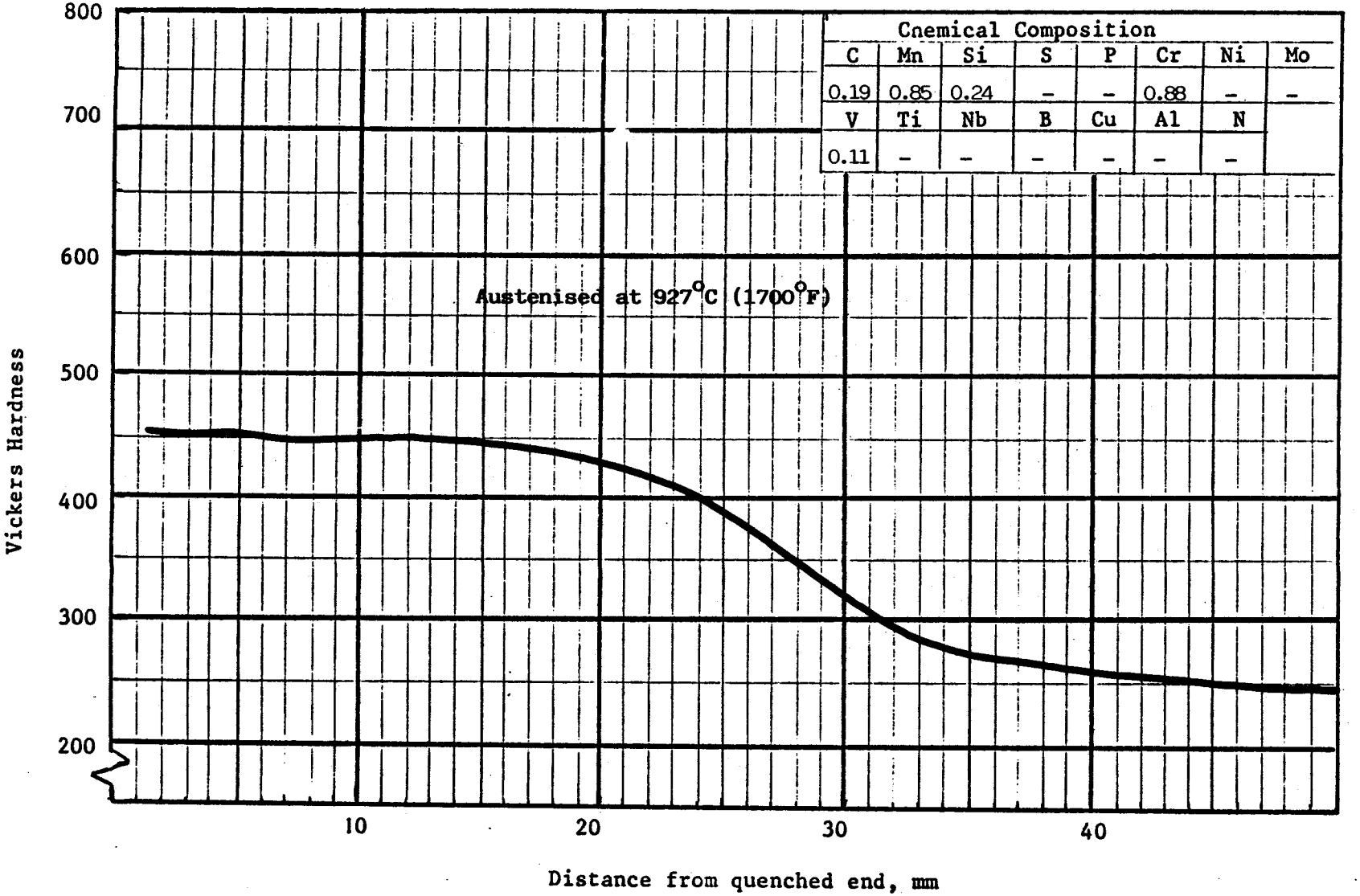
Steel 2



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.22	1.24	0.22	0.013	0.001	–	–	0.02
V	Ti	Nb	B	Cu	Al	N	
0.13	–	–	–	–	–	–	

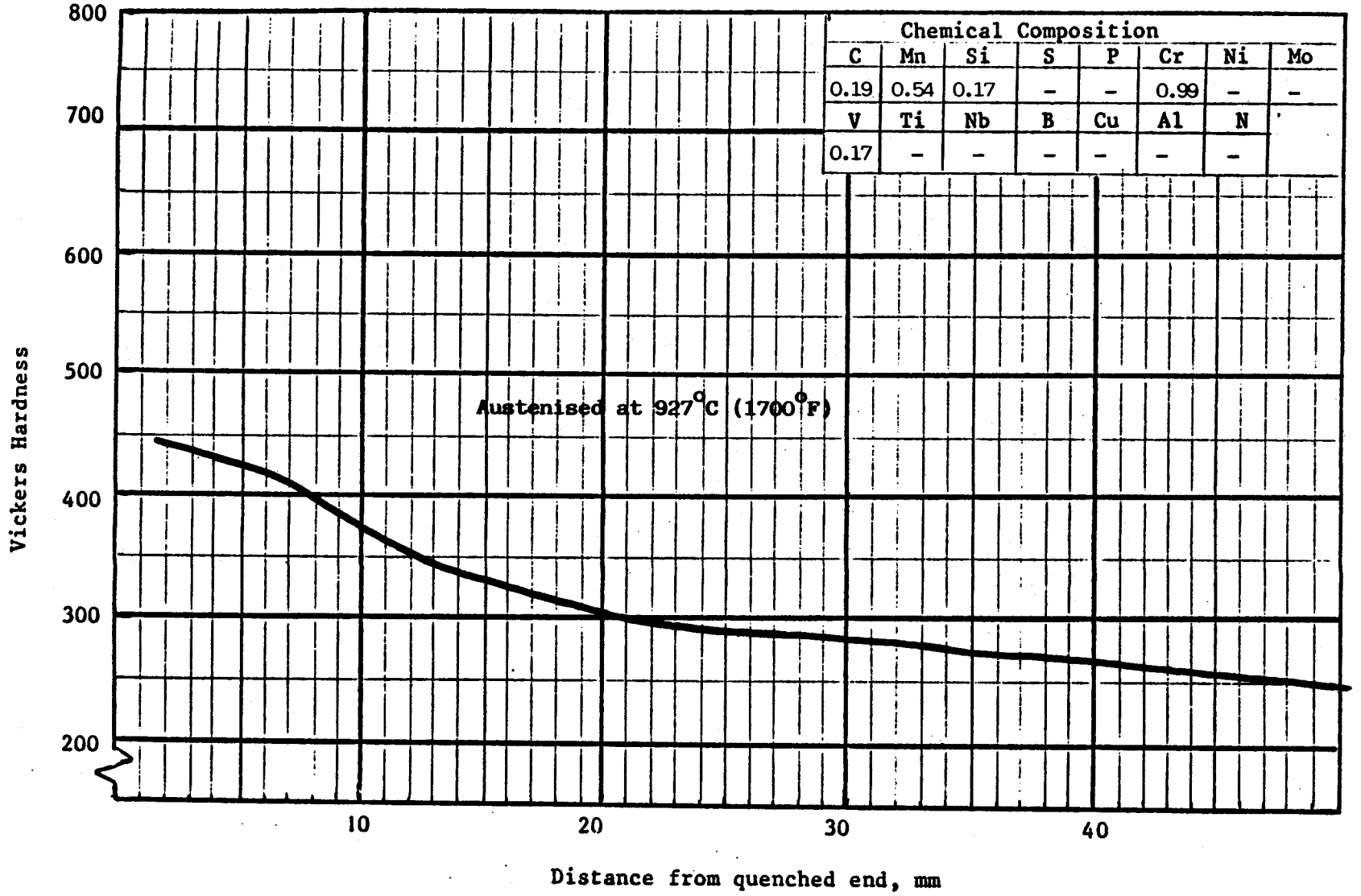
Source: Foote Mineral Company, U.S.A.
Van ref: 58

Steel 3



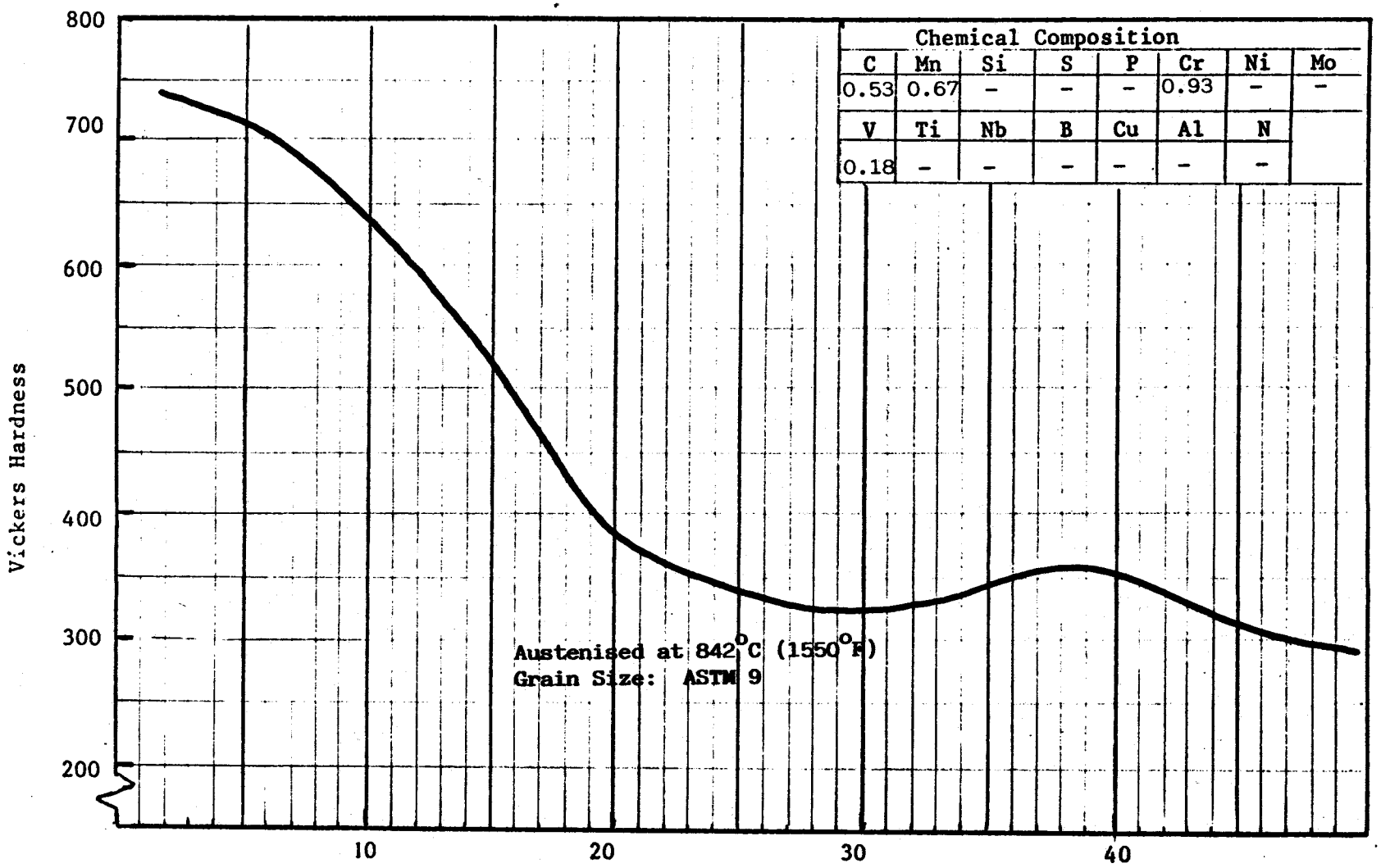
Source: F. F. Franklin, Materials and Methods, June 1946
Van ref: 84

Steel 4



Source: F. F. Franklin, Materials and Methods, June 1946
Van ref: 83

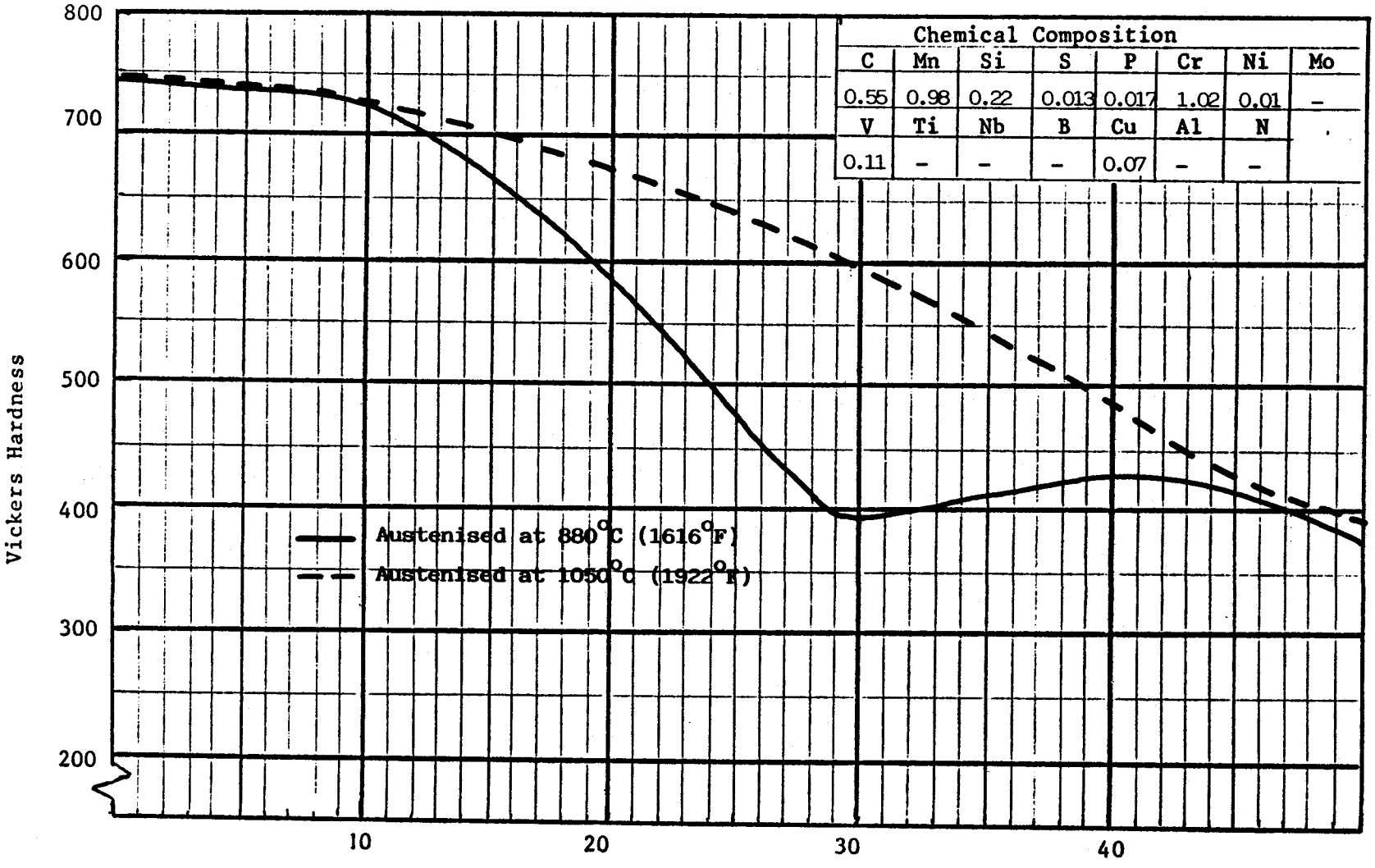
Steel 5



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.53	0.67	-	-	-	0.93	-	-
V	Ti	Nb	B	Cu	Al	N	
0.18	-	-	-	-	-	-	

Source: Atlas of Isothermal and Cooling Transformation Diagrams, ASM,1977
Van ref: 2

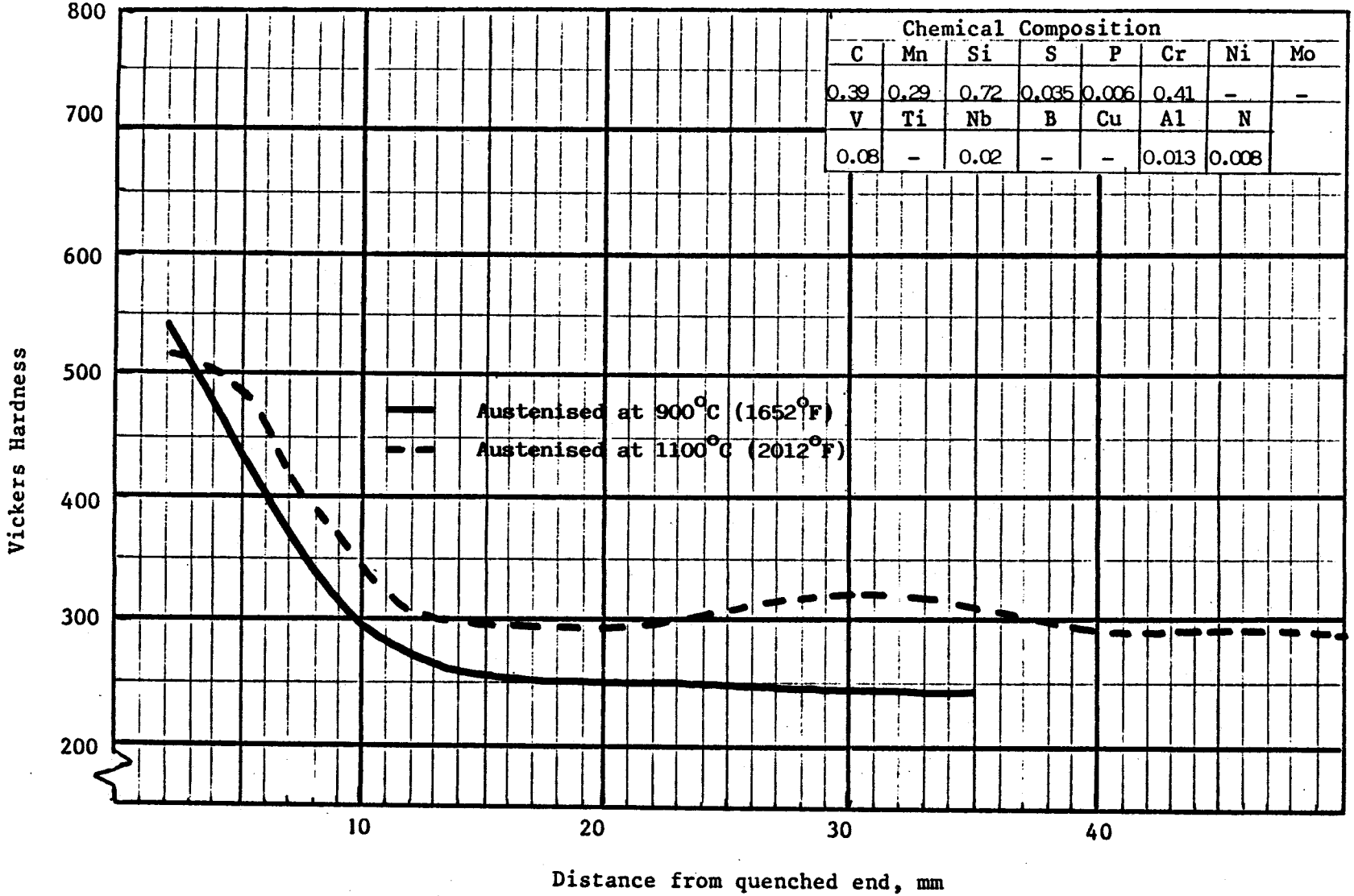
Steel 6



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.55	0.98	0.22	0.013	0.017	1.02	0.01	–
V	Ti	Nb	B	Cu	Al	N	
0.11	–	–	–	0.07	–	–	

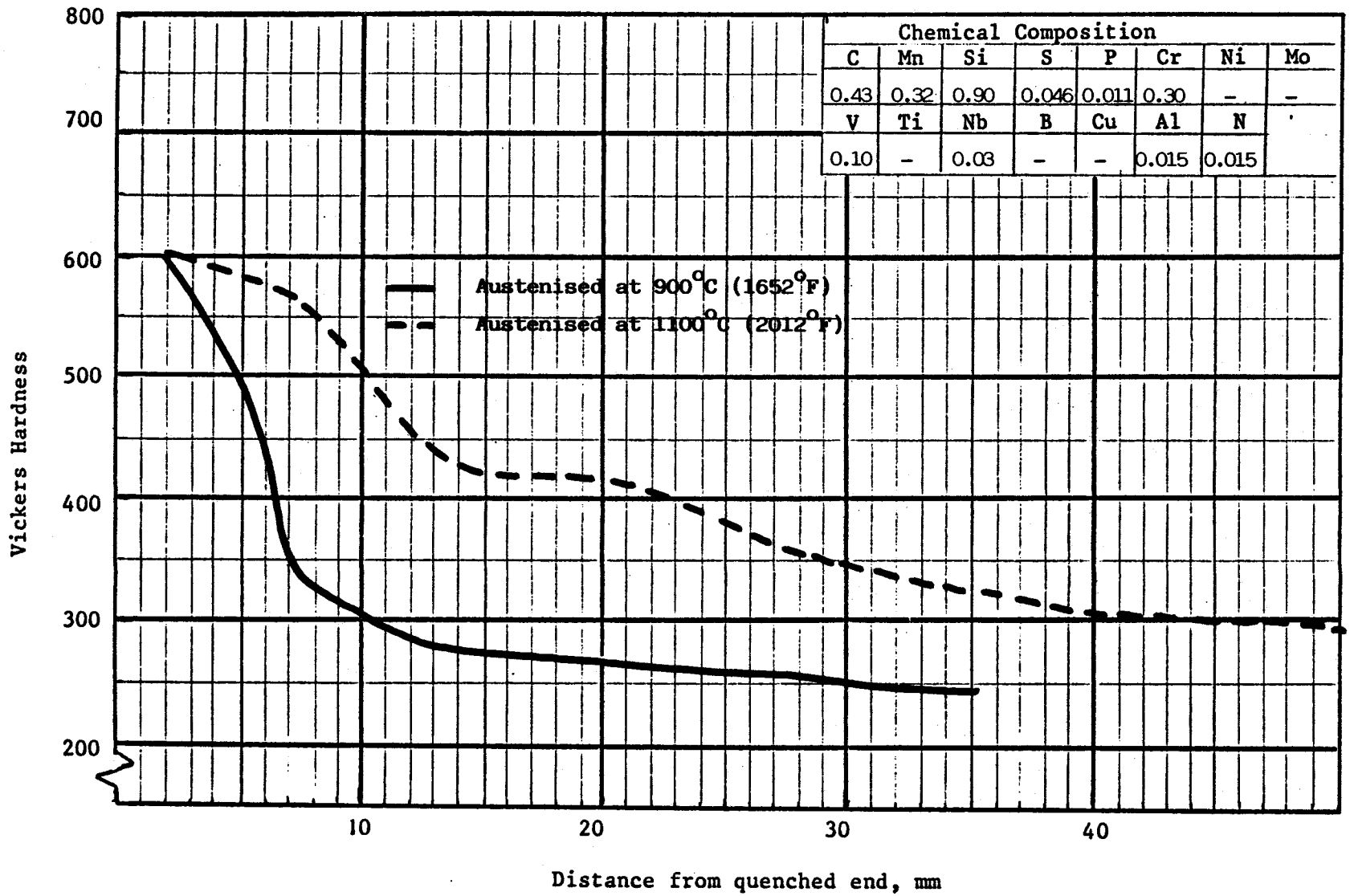
Source: Atlas zur Warmbehandlung der Stahle, Max Planck Institut fur Eisenforschung, 1958
Van ref: 5

Steel 7



Source: A. Steinen and S. Engineer, TEW Berichte 4 (1) 1978 21 - 28
Van ref: 81

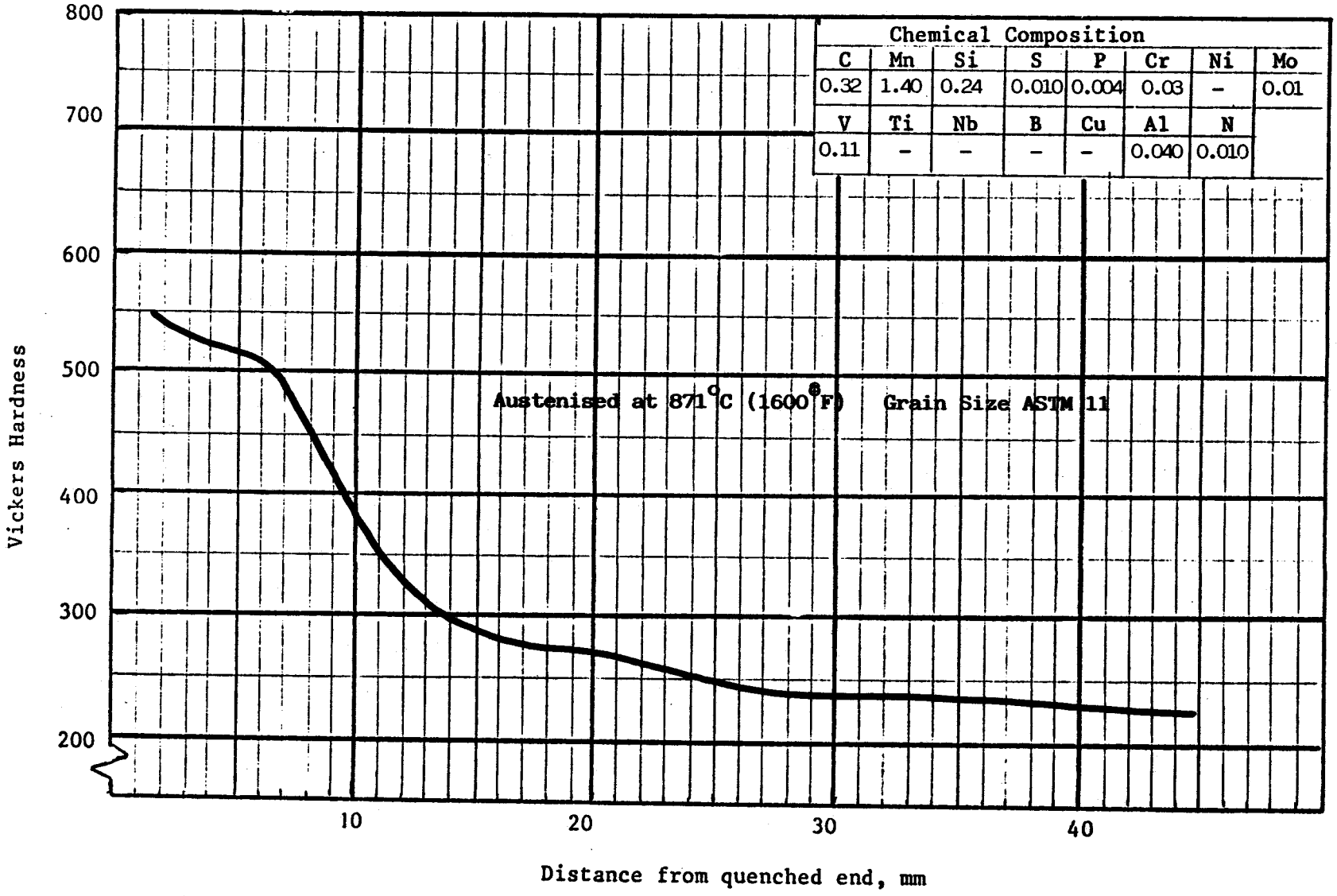
Steel 8



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.43	0.32	0.90	0.046	0.011	0.30	–	–
V	Ti	Nb	B	Cu	Al	N	
0.10	–	0.03	–	–	0.015	0.015	

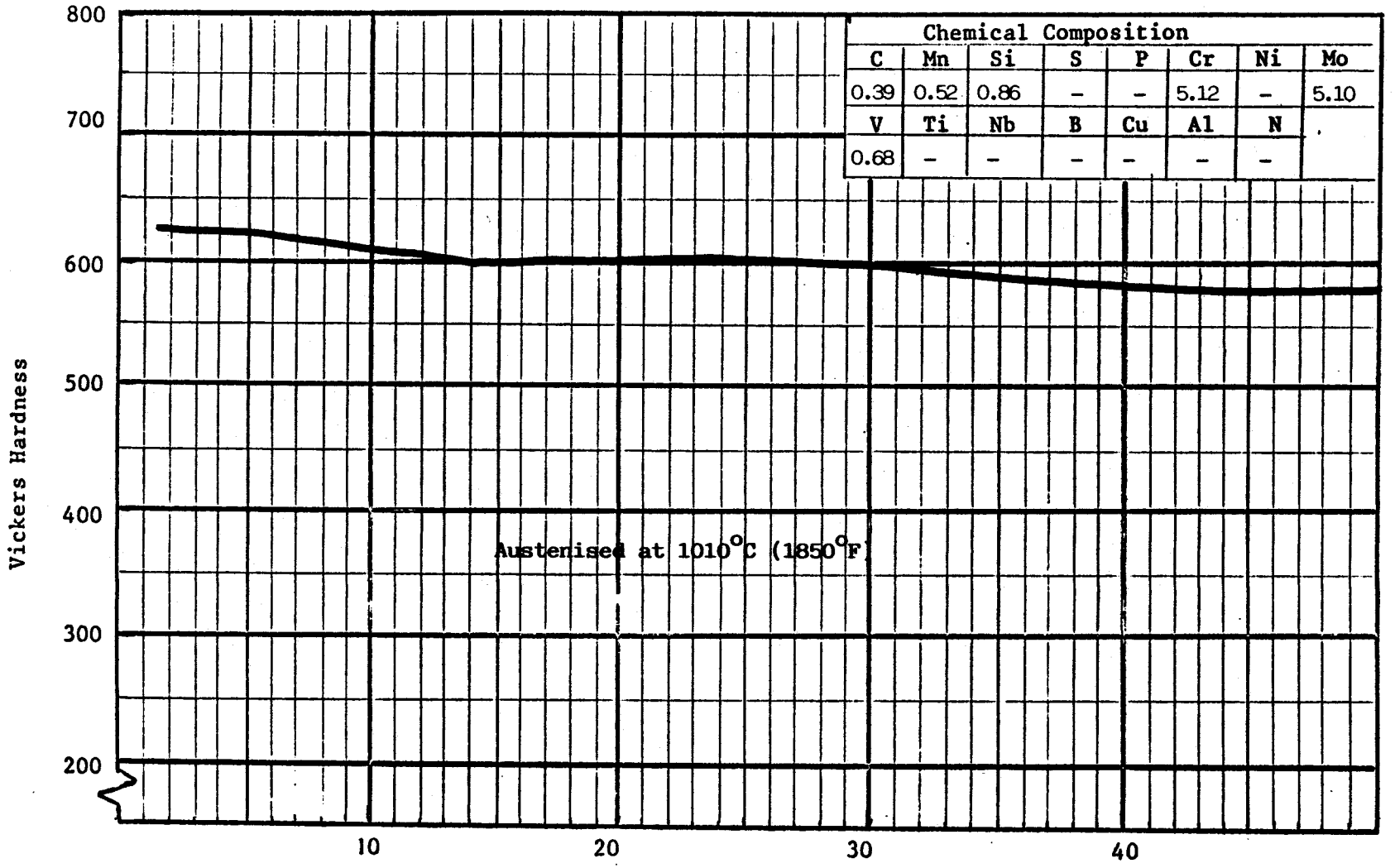
Source: A. Steinen and S. Engineer, TEW Berichte 4 (1) 1978 21 - 28
Van ref: 82

Steel 9



Source: Diagram determined by Foote Mineral Company, USA.
Van ref: 31

Steel 10

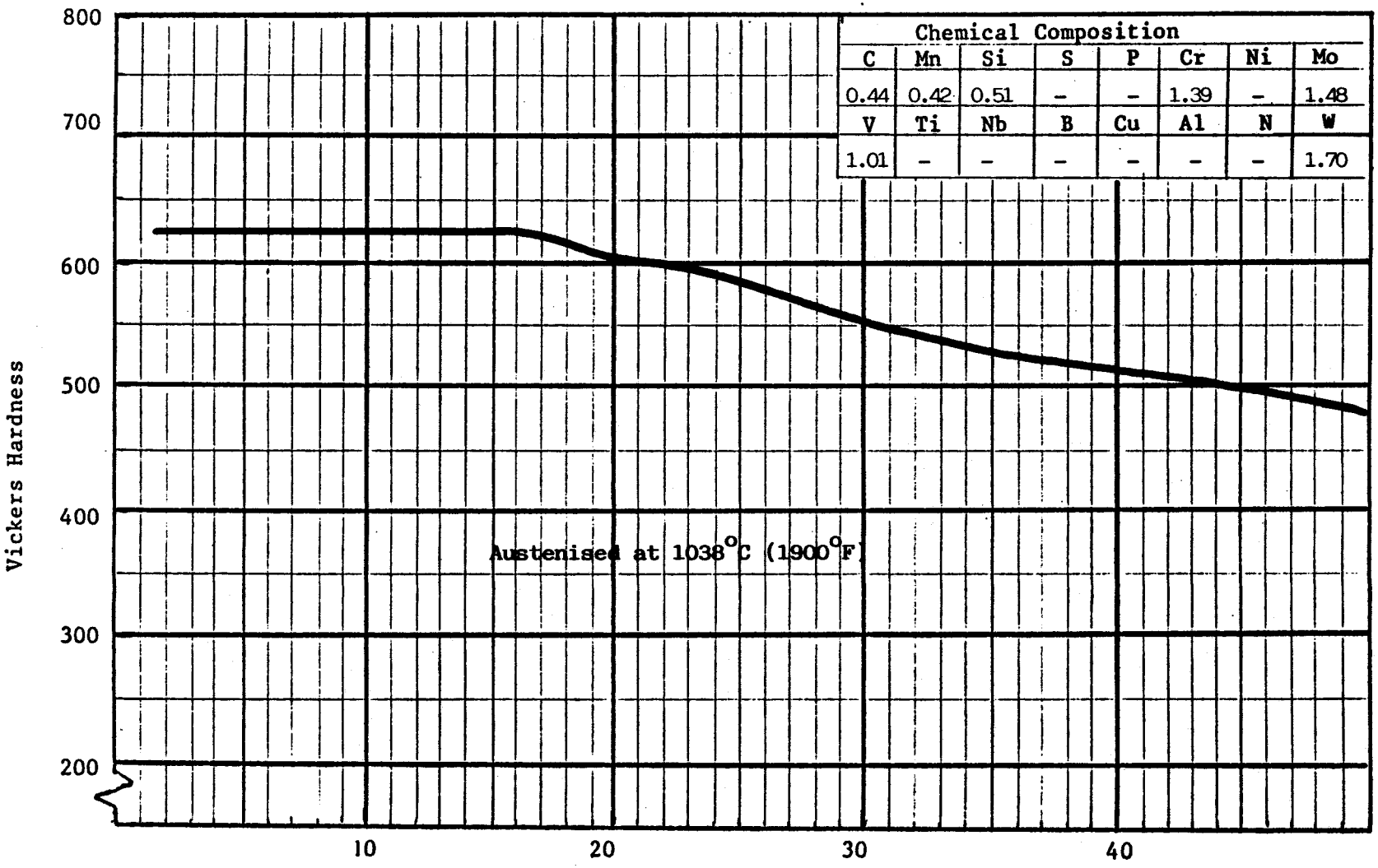


Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.39	0.52	0.86	–	–	5.12	–	5.10
V	Ti	Nb	B	Cu	Al	N	
0.68	–	–	–	–	–	–	

Source: C. F. Jatcak, in "Hardenability Concepts with Applications to Steel", eds. D. V. Doane and J. s. Kirkaldy, TMS-AIME, 1978, pp. 334-346.

Van ref: 92

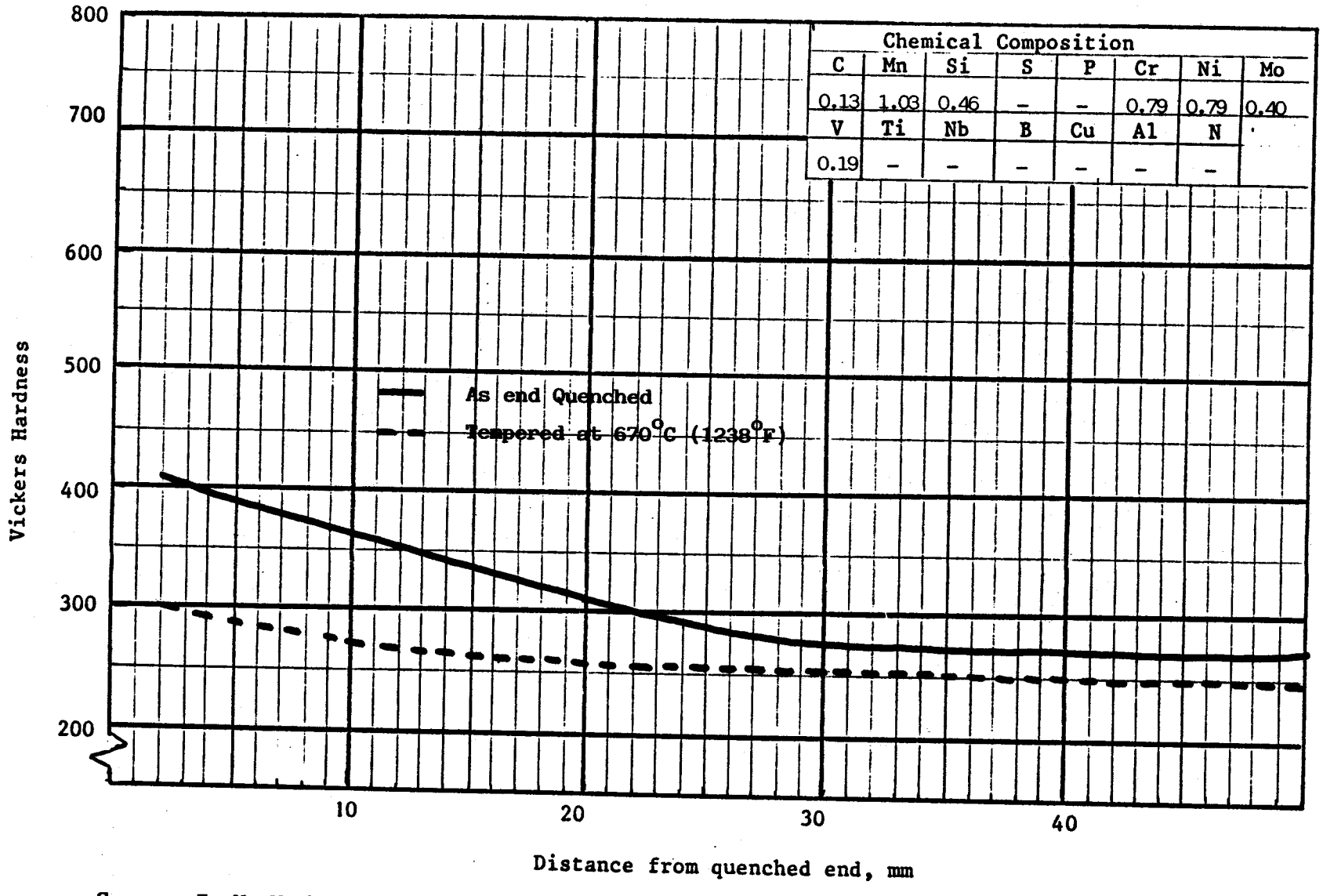
Steel 11



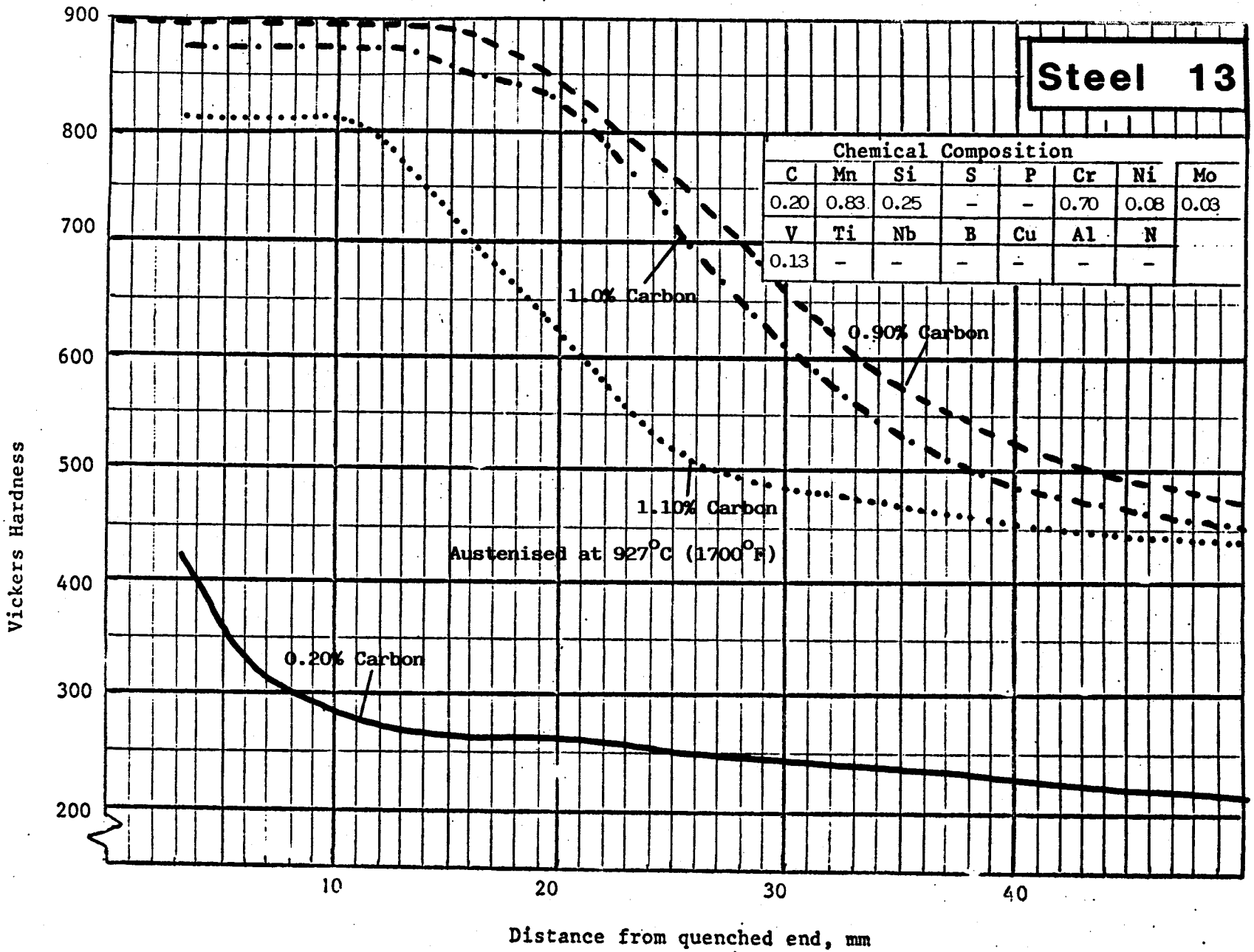
Source: C. F. Jatcak, in "Hardenability Concepts with Applications to Steel", eds. D. V. Doane and J. S. Kirkaldy, TMS-AIME, 1978, pp.334-346.

Van ref: 94

Steel 12

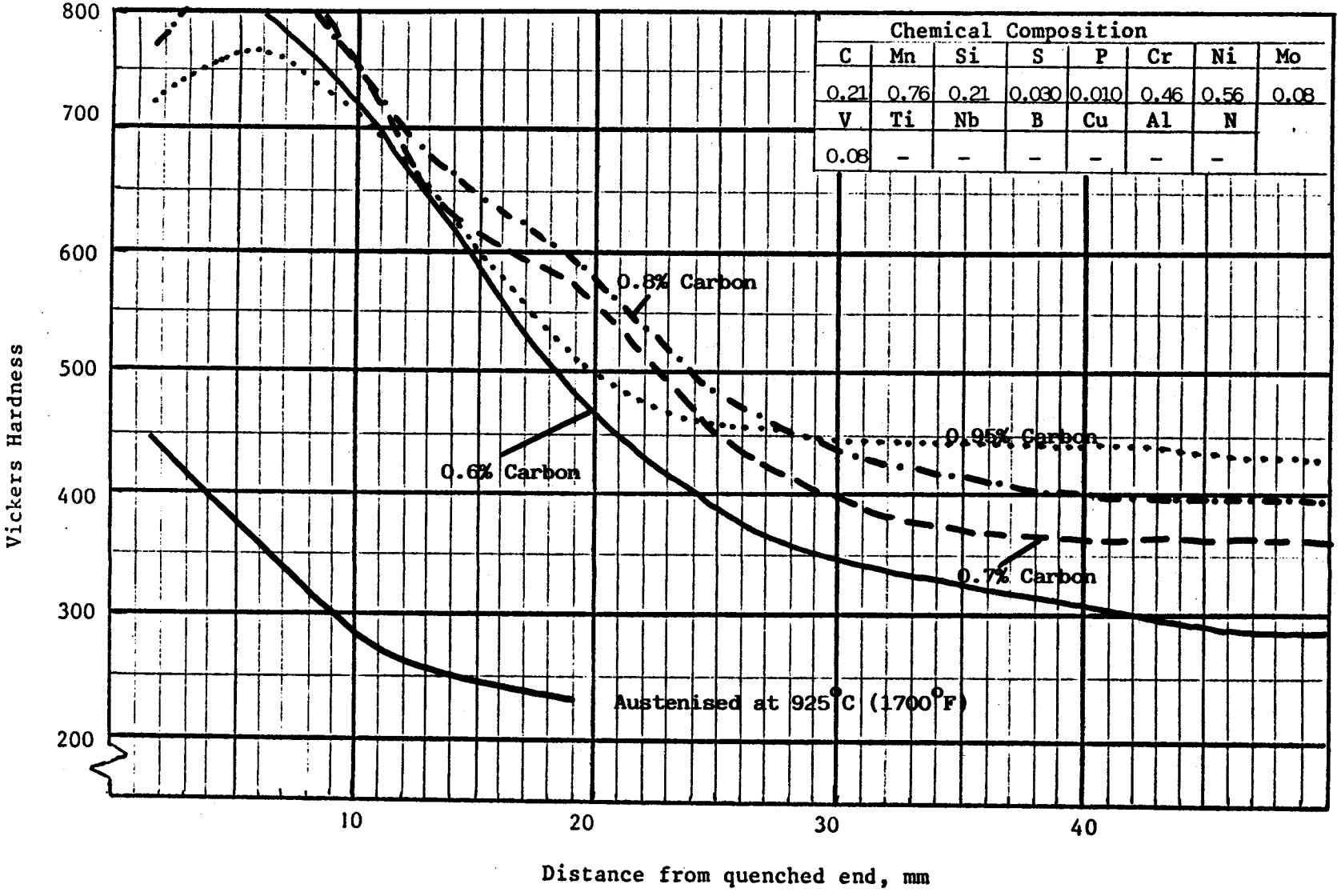


Source: I. M. Mackenzie, in "Symposium on Low Alloy High Strength Steels", Metallurg Co., 1970, p. 127
Van ref: 98



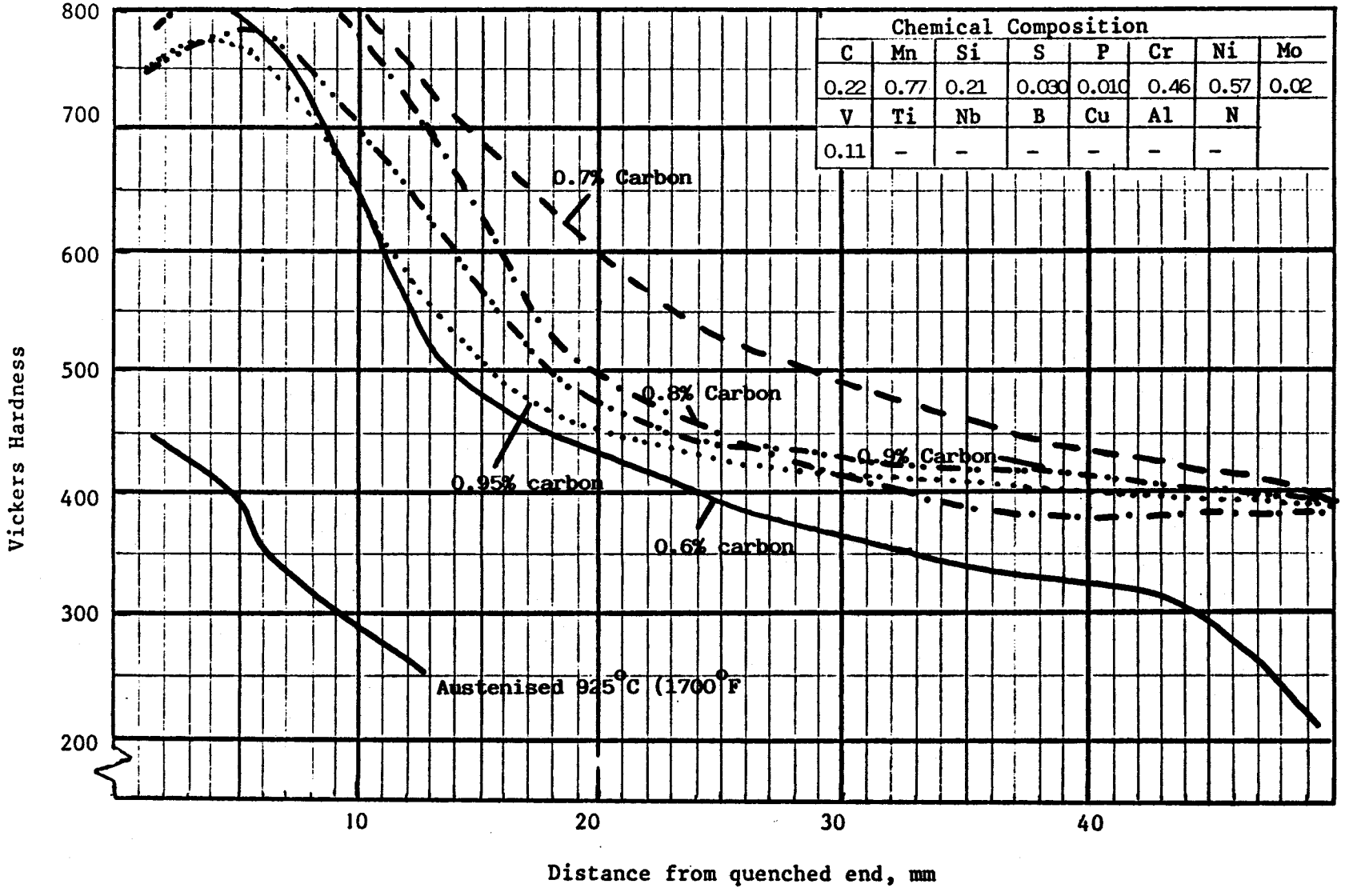
Source: "Atlas-Hardenability of Carburized Steels",Climax Molybdenum, 1960, p. 109
Van ref: 99

Steel 14



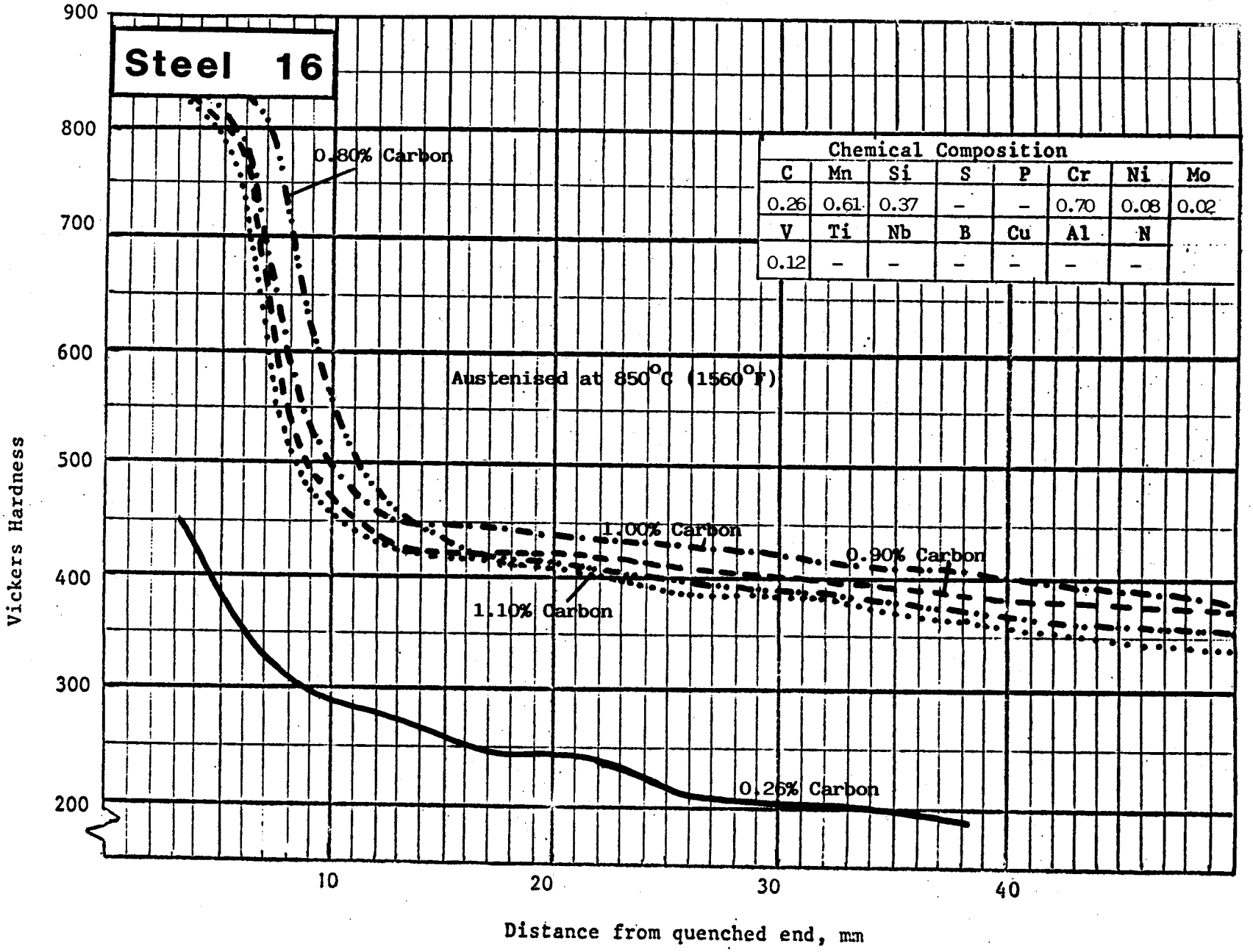
Source: Diagram determined by International Harvester Company.
Van ref: 8

Steel 15



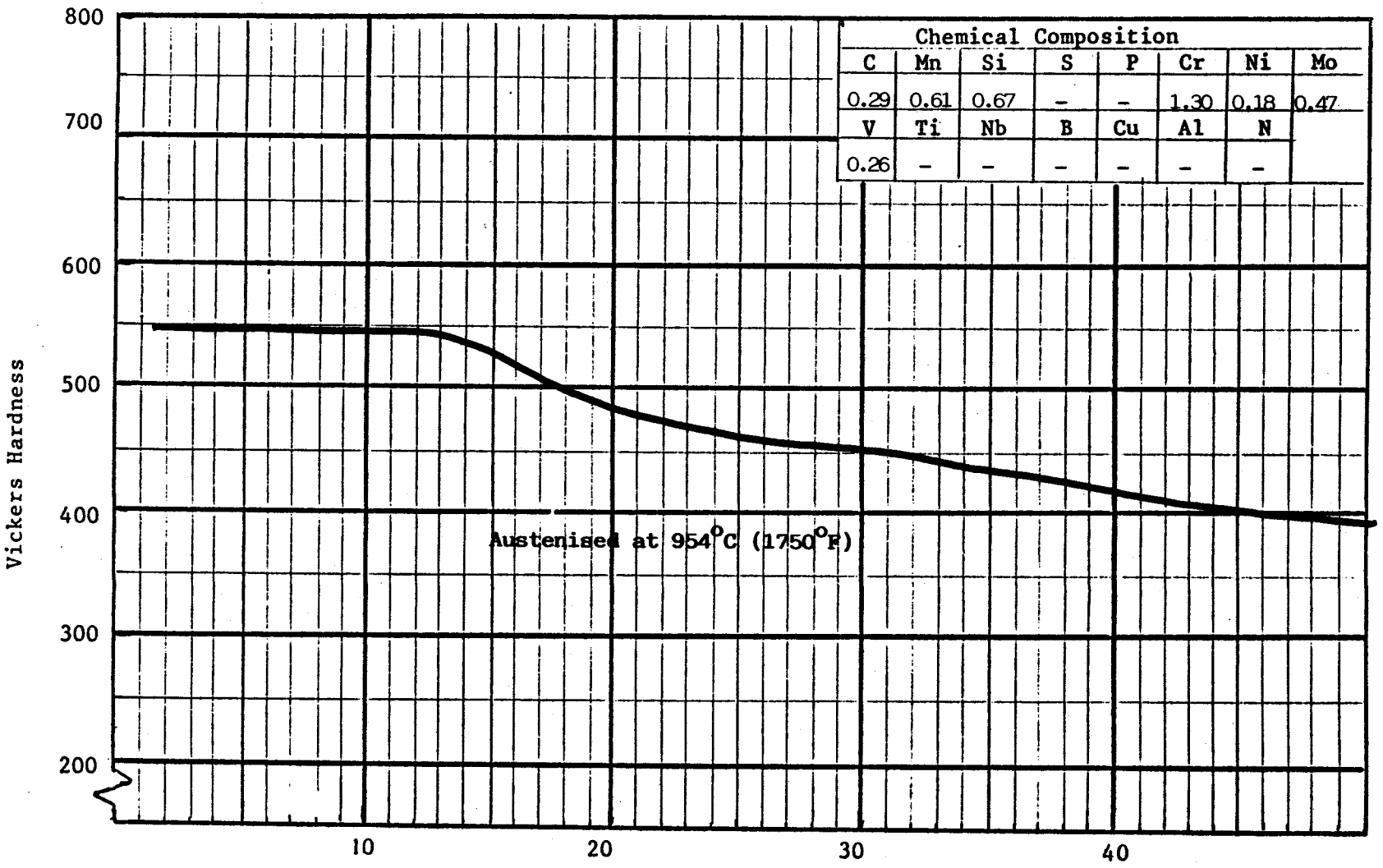
Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.22	0.77	0.21	0.030	0.010	0.46	0.57	0.02
V	Ti	Nb	B	Cu	Al	N	
0.11	-	-	-	-	-	-	

Source: Diagram determined by International Harvester Company.
Van ref: 7



Source: "Atlas-Hardenability of Carburized Steels", Climax Molybdenum, 1960, p. 110
Van ref: 100

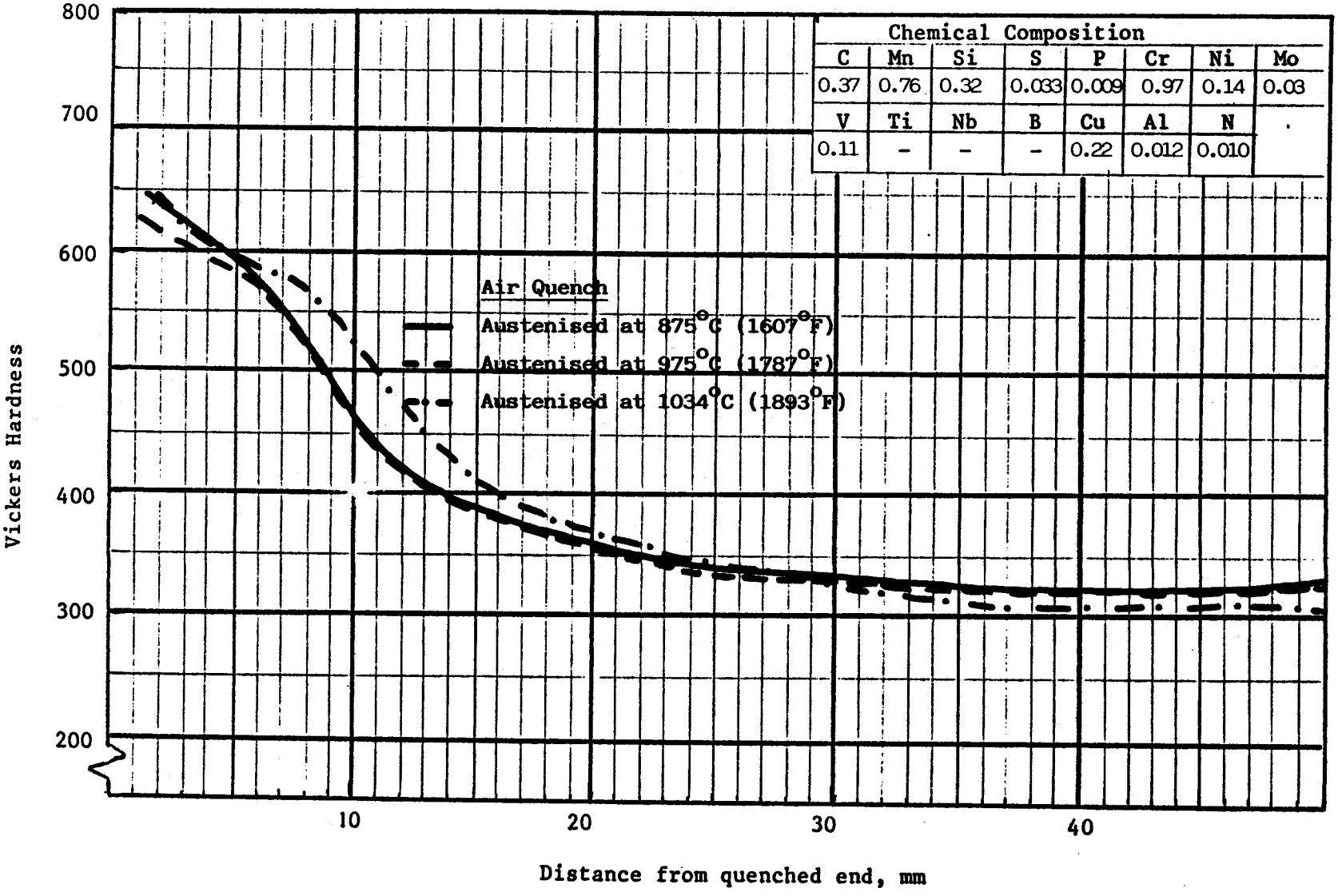
Steel 17



Source: C. F. Jatcak, in "Hardenability Concepts with Applications to Steel", Eds. D. V. Doane and J. S. Kirkaldy, TMS-AIME, 1978, pp. 334-346.

Van ref: 89

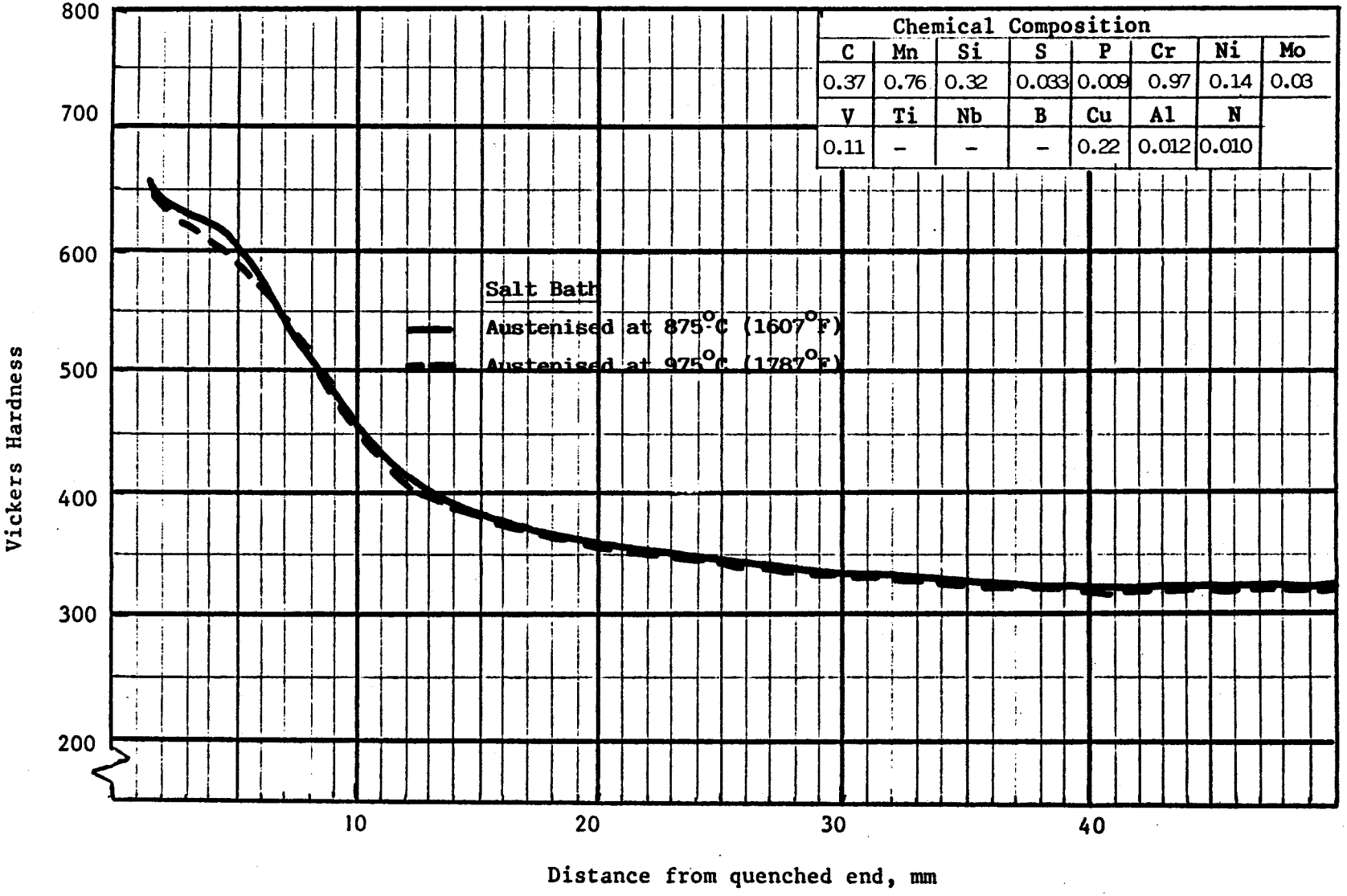
Steel 18a



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.37	0.76	0.32	0.033	0.009	0.97	0.14	0.03
V	Ti	Nb	B	Cu	Al	N	
0.11	-	-	-	0.22	0.012	0.010	

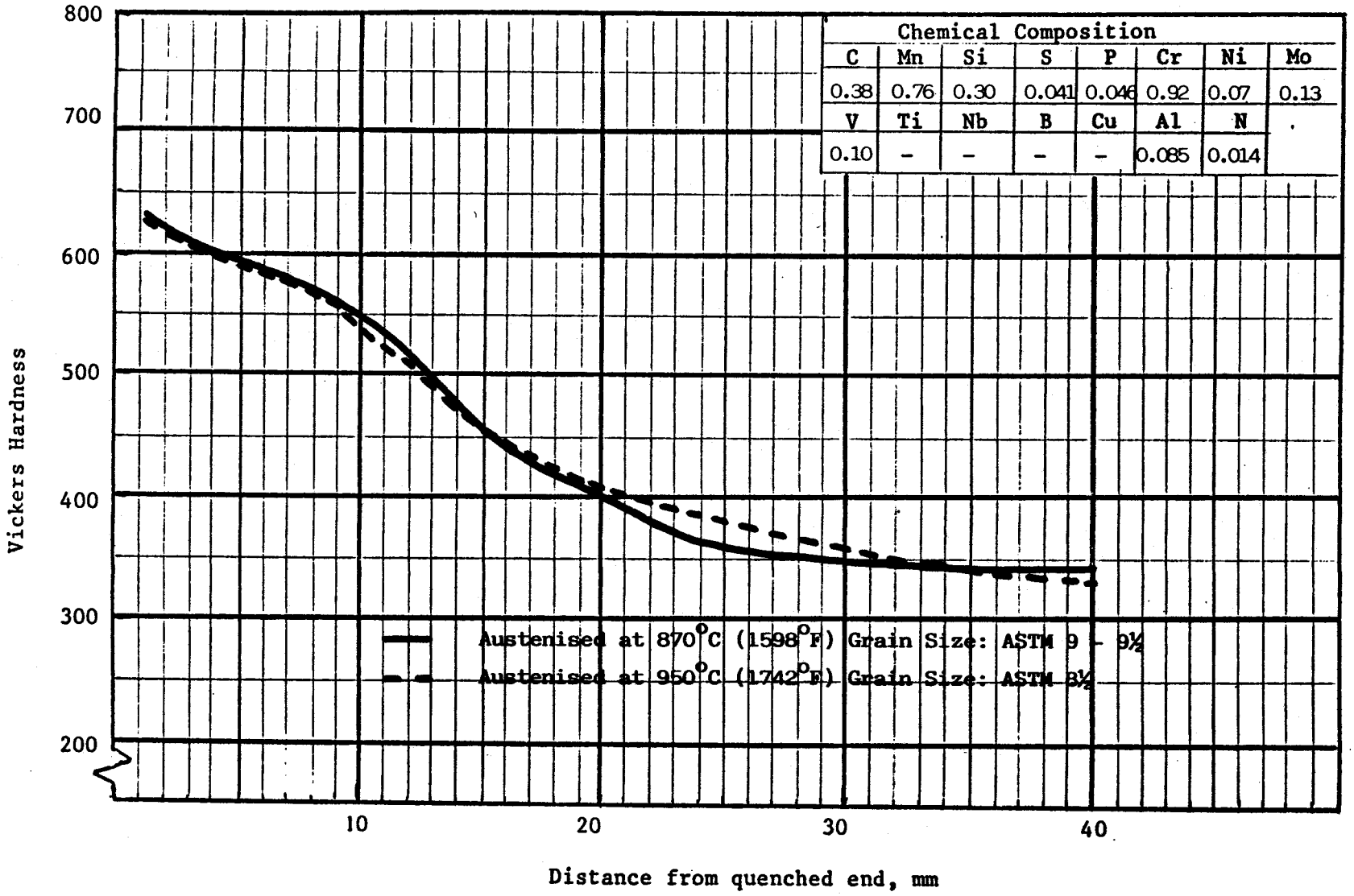
Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 38

Steel 18b



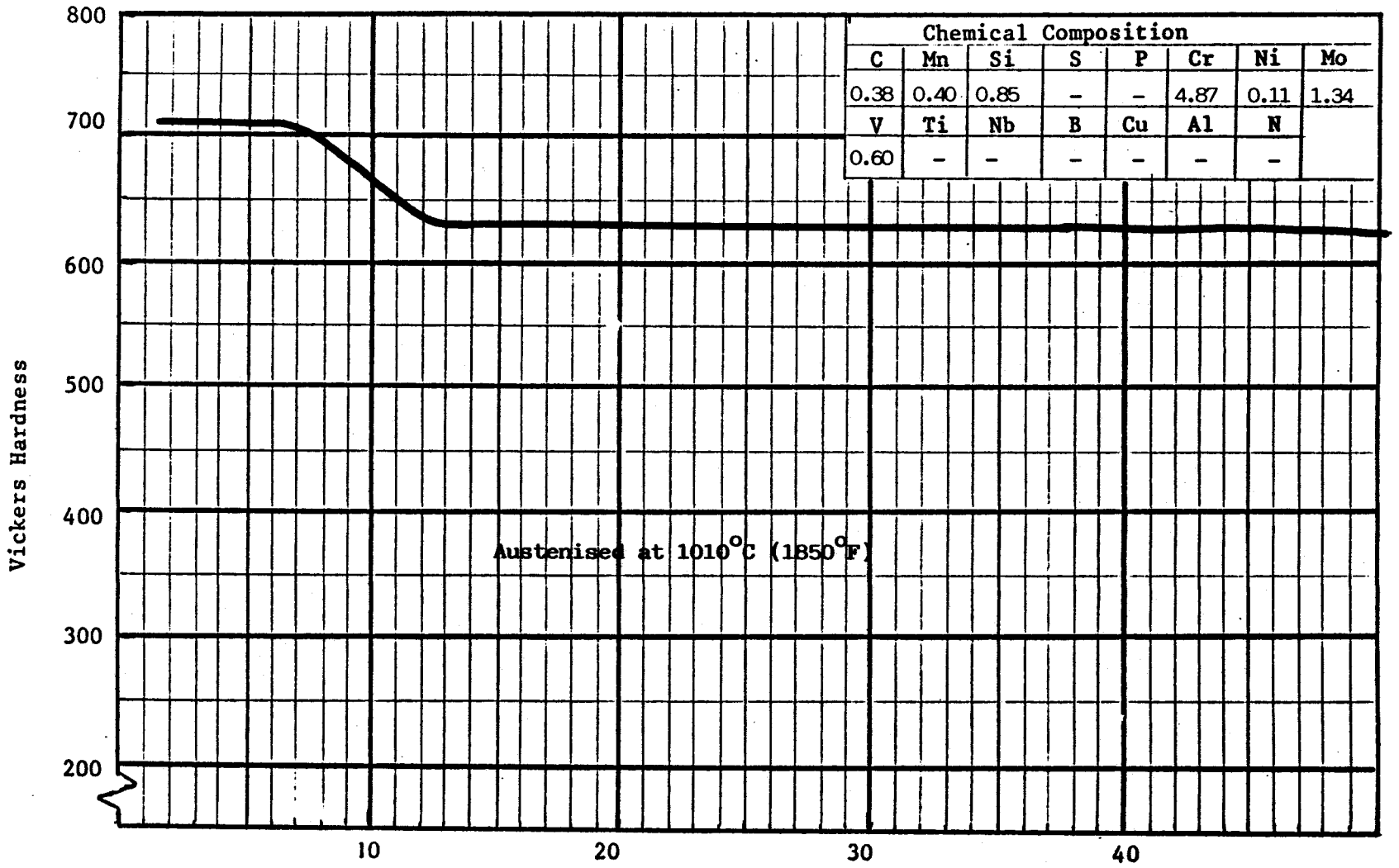
Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 38

Steel 19



Source: Diagram determined by Sheffield University, England.
Van ref: 103

Steel 20

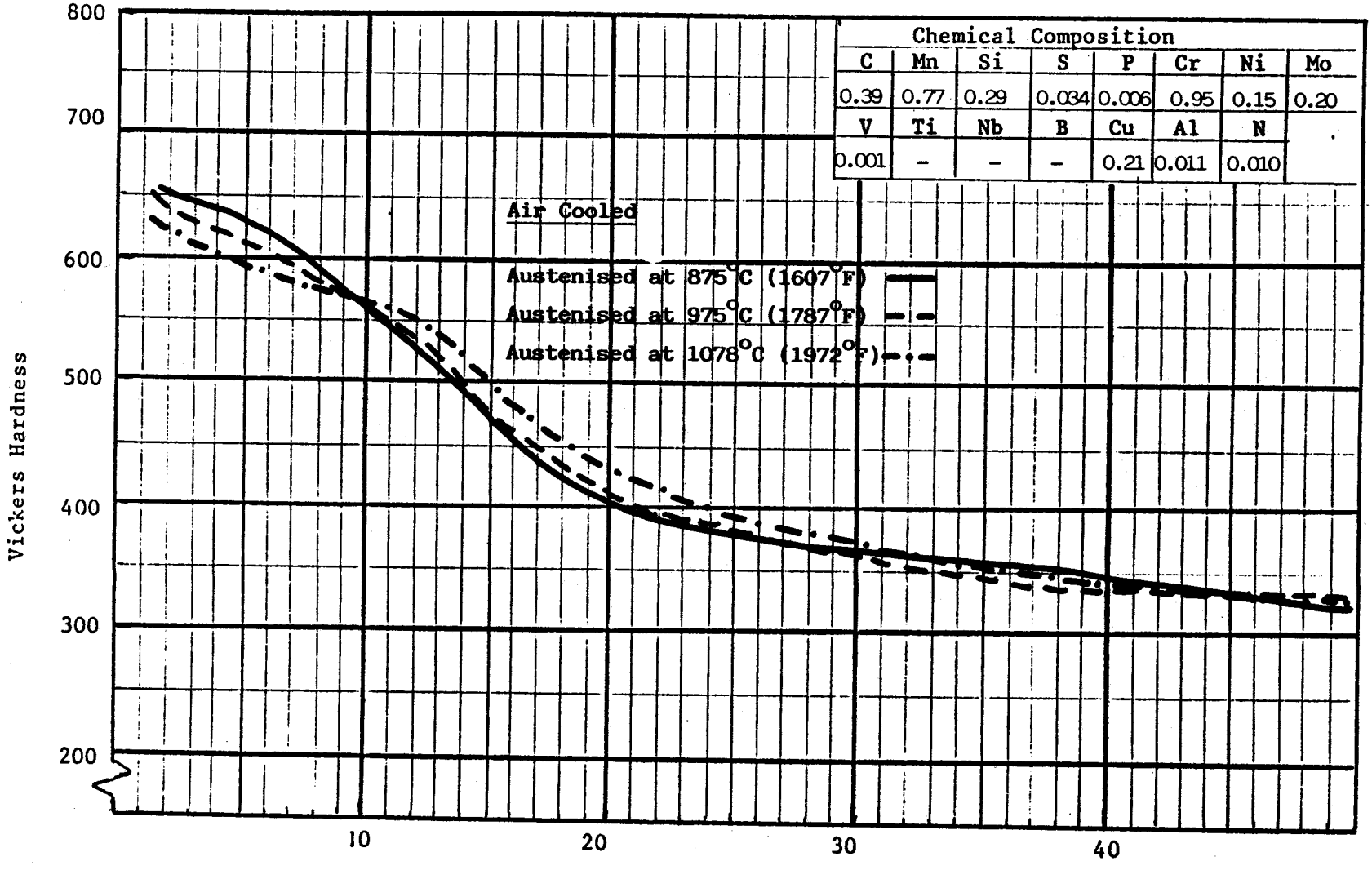


Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.38	0.40	0.85	-	-	4.87	0.11	1.34
V	Ti	Nb	B	Cu	Al	N	
0.60	-	-	-	-	-	-	

Source: C. F. Jatcak, in "Hardenability Concepts with Applications to Steel", Eds. D. V. Doane and J. S. Kirkaldy, TMS-AIME, 1978, pp. 334-346.

Van ref: 91

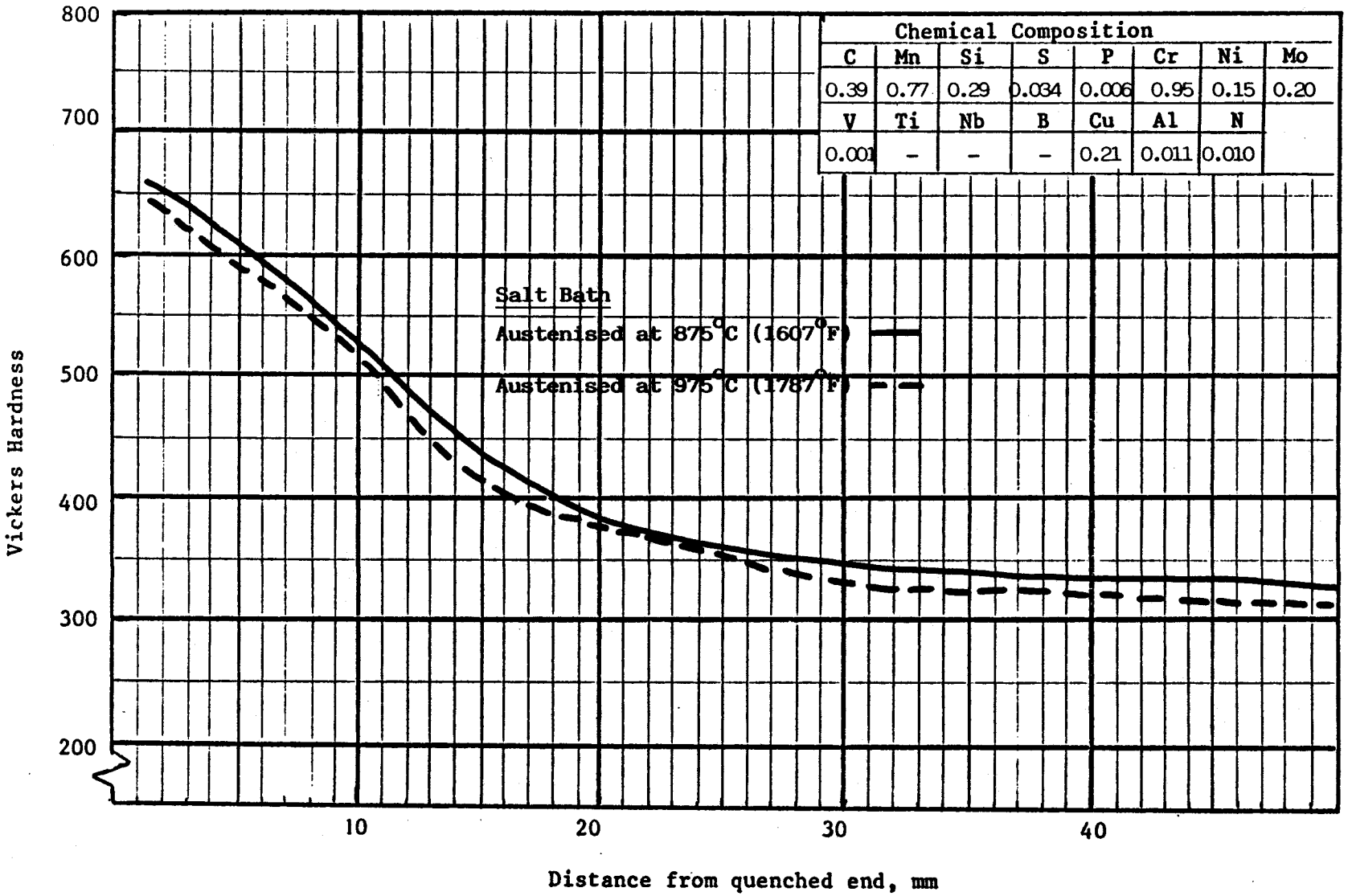
Steel 21a



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.39	0.77	0.29	0.034	0.006	0.95	0.15	0.20
V	Ti	Nb	B	Cu	Al	N	
0.001	-	-	-	0.21	0.011	0.010	

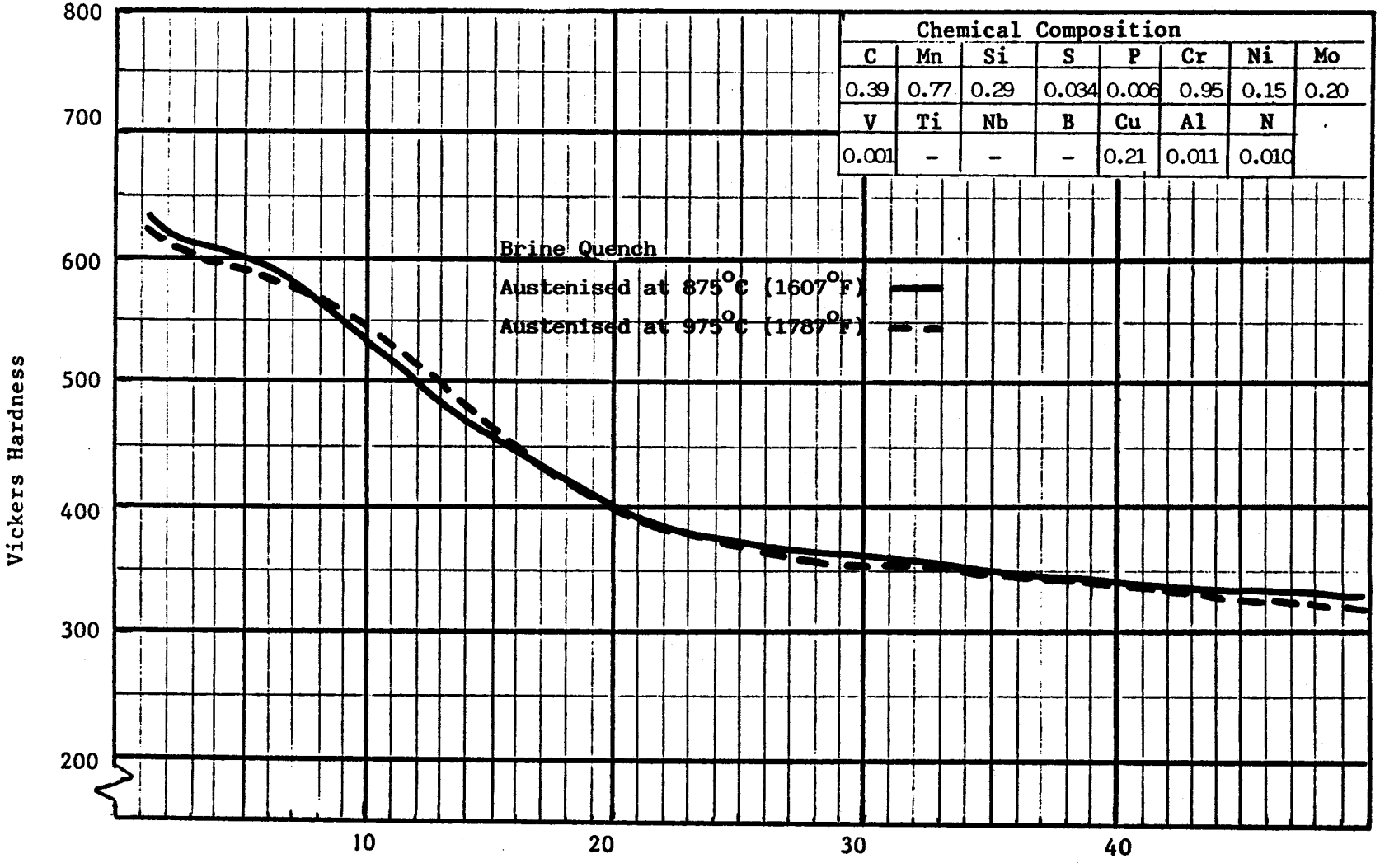
Source: Diagram determined by Institutet for Metallforskning, Sweden.
Van ref: 36

Steel 21b



Source: Diagram determined by Institutet for Metallforskning, Sweden.
Van ref: 36

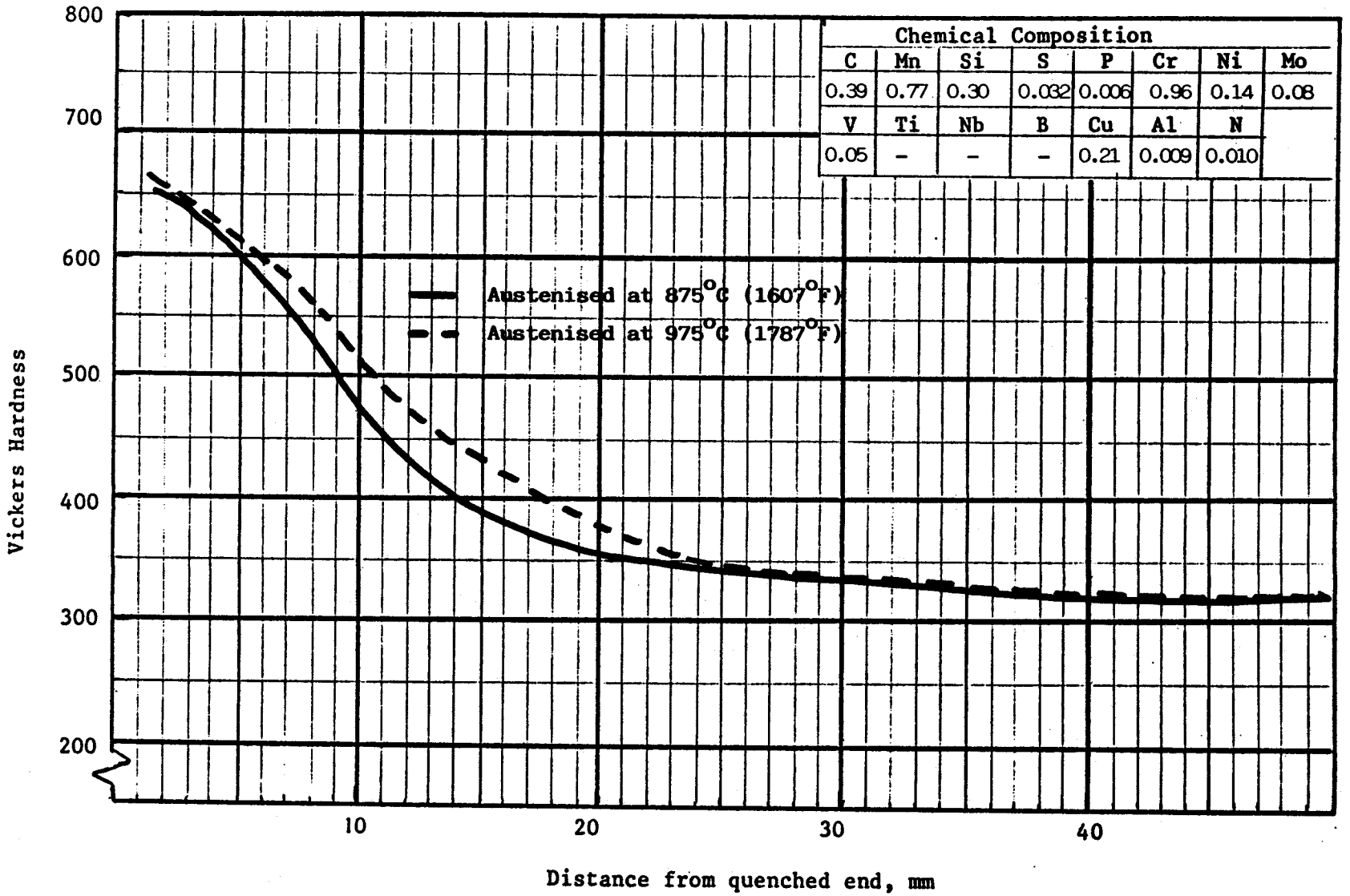
Steel 21c



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.39	0.77	0.29	0.034	0.006	0.95	0.15	0.20
V	Ti	Nb	B	Cu	Al	N	
0.001	-	-	-	0.21	0.011	0.010	

Source: Diagram determined by Institutet for Metallforskning, Sweden.
Van ref: 36

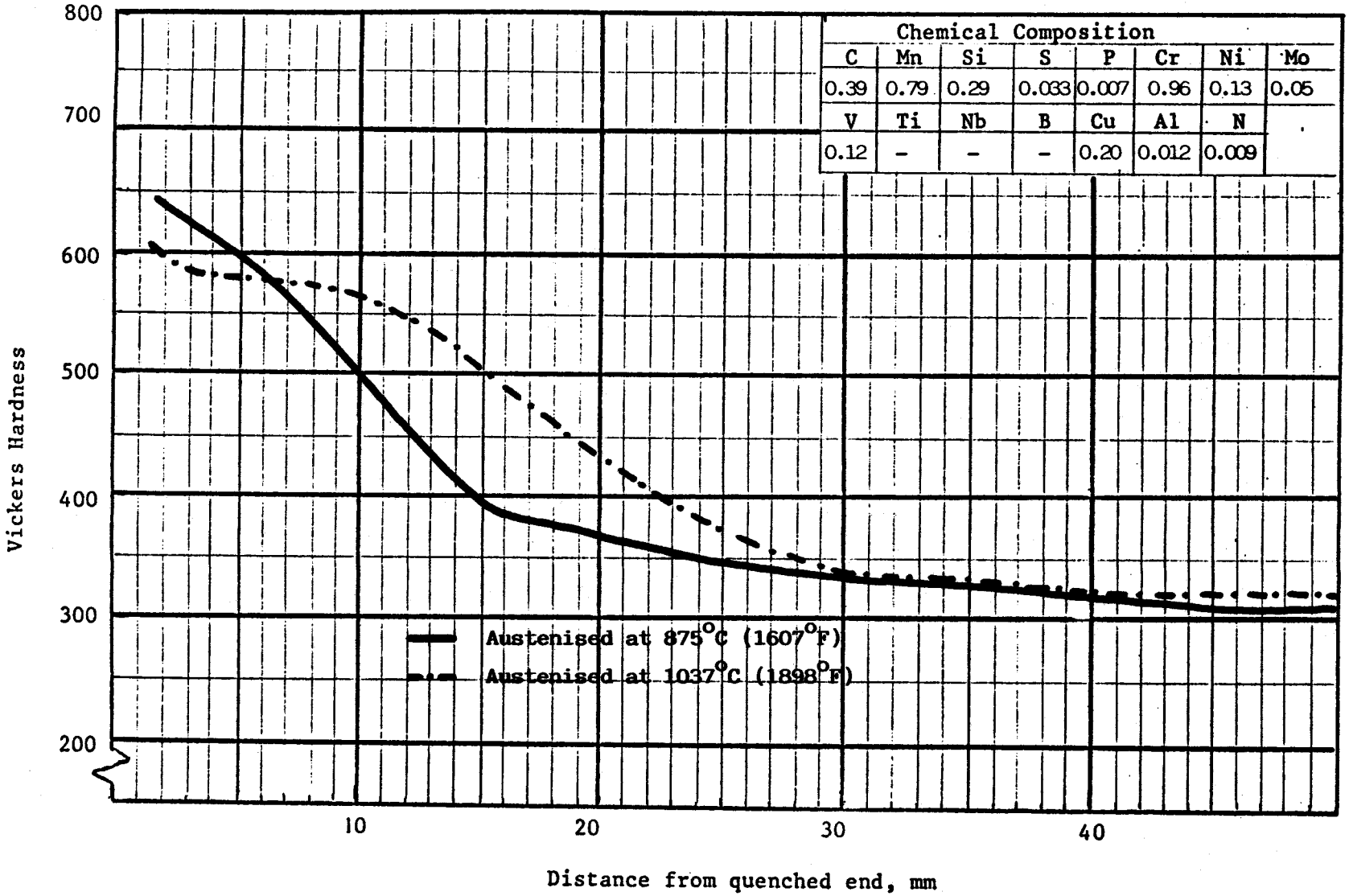
Steel 22



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.39	0.77	0.30	0.032	0.006	0.96	0.14	0.08
V	Ti	Nb	B	Cu	Al	N	
0.05	-	-	-	0.21	0.009	0.010	

Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 39

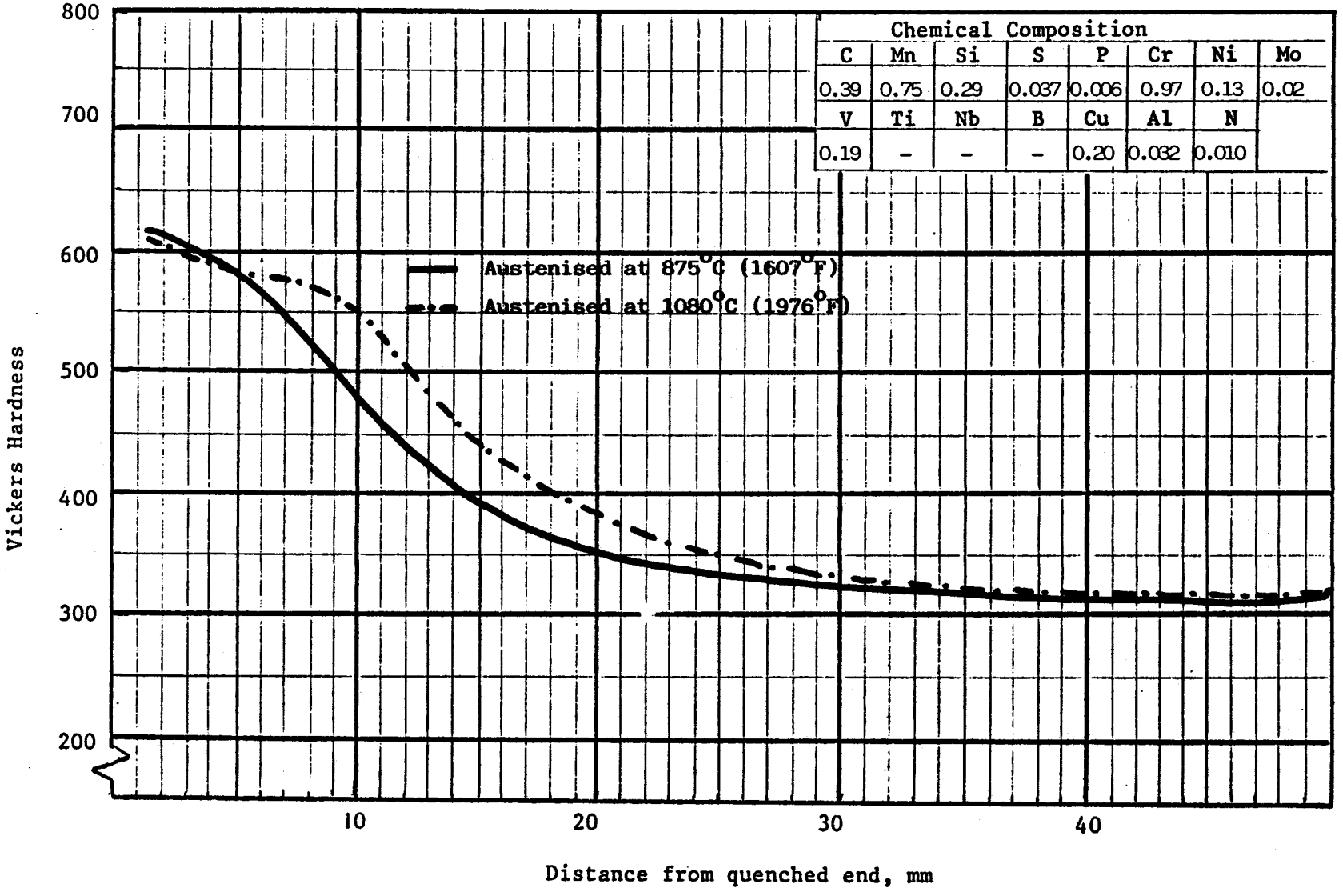
Steel 23



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.39	0.79	0.29	0.033	0.007	0.96	0.13	0.05
V	Ti	Nb	B	Cu	Al	N	
0.12	-	-	-	0.20	0.012	0.009	

Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 57

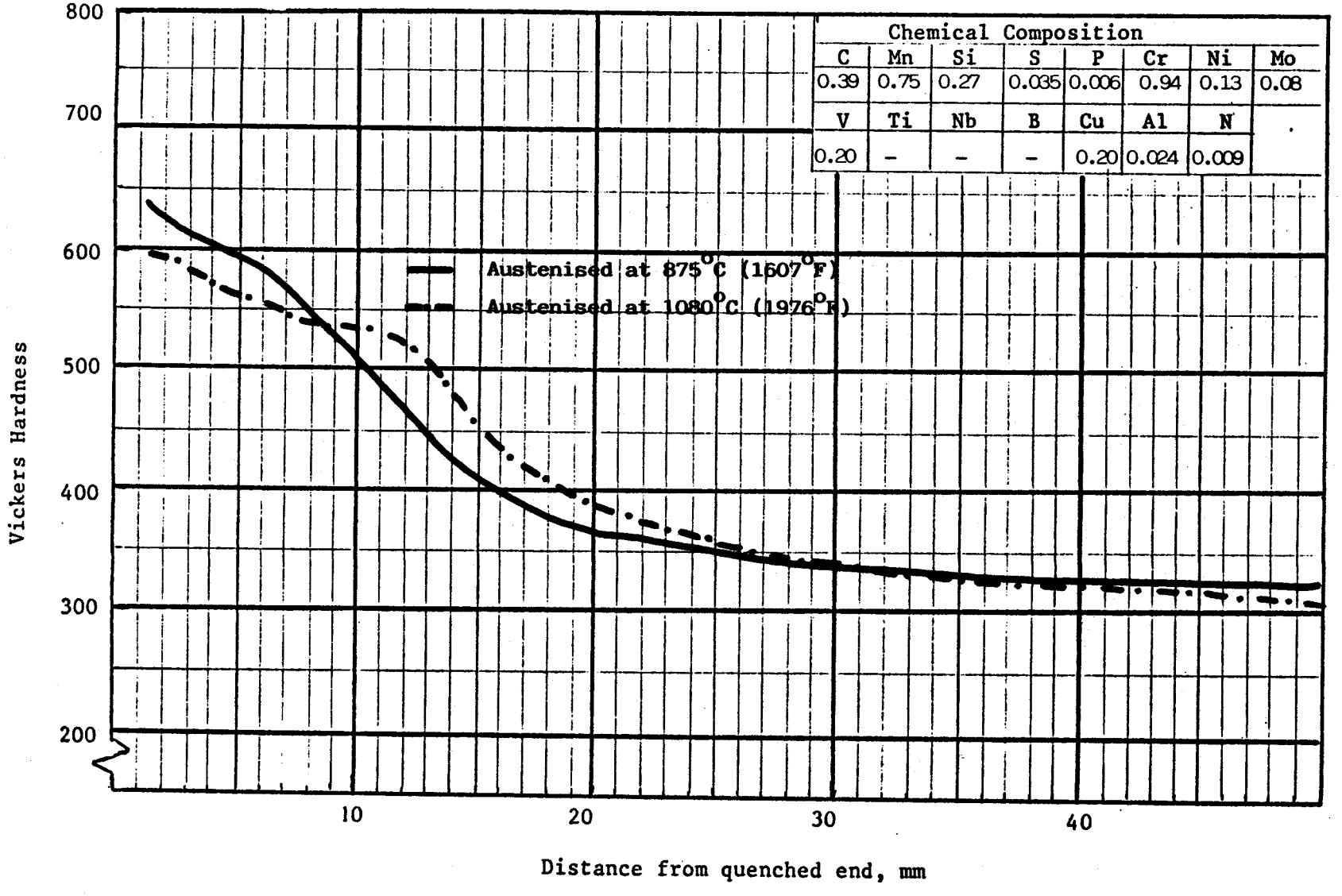
Steel 24



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.39	0.75	0.29	0.037	0.006	0.97	0.13	0.02
V	Ti	Nb	B	Cu	Al	N	
0.19	-	-	-	0.20	0.032	0.010	

Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 50

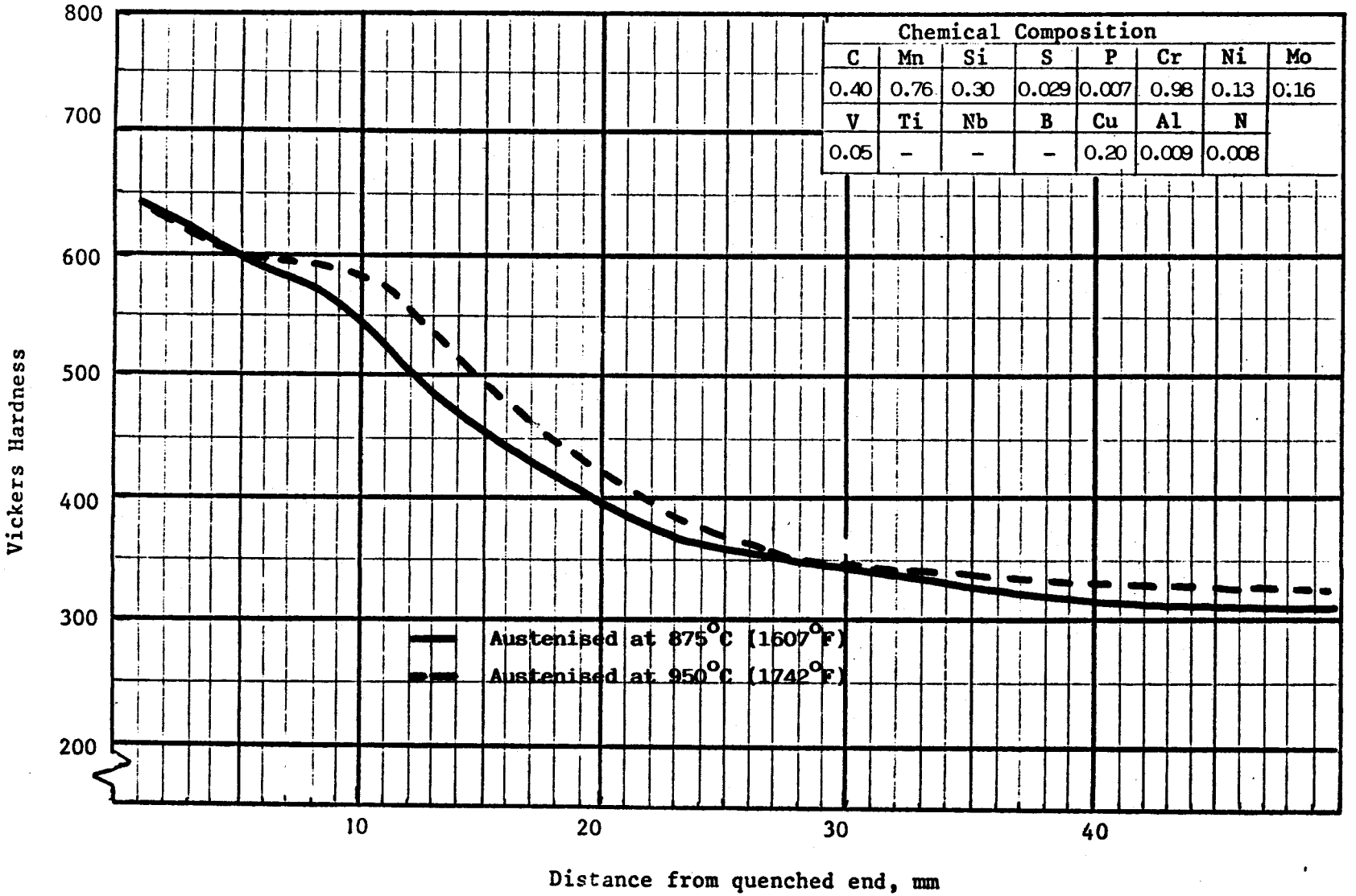
Steel 25



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.39	0.75	0.27	0.035	0.006	0.94	0.13	0.08
V	Ti	Nb	B	Cu	Al	N	
0.20	–	–	–	0.20	0.024	0.009	

Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 51

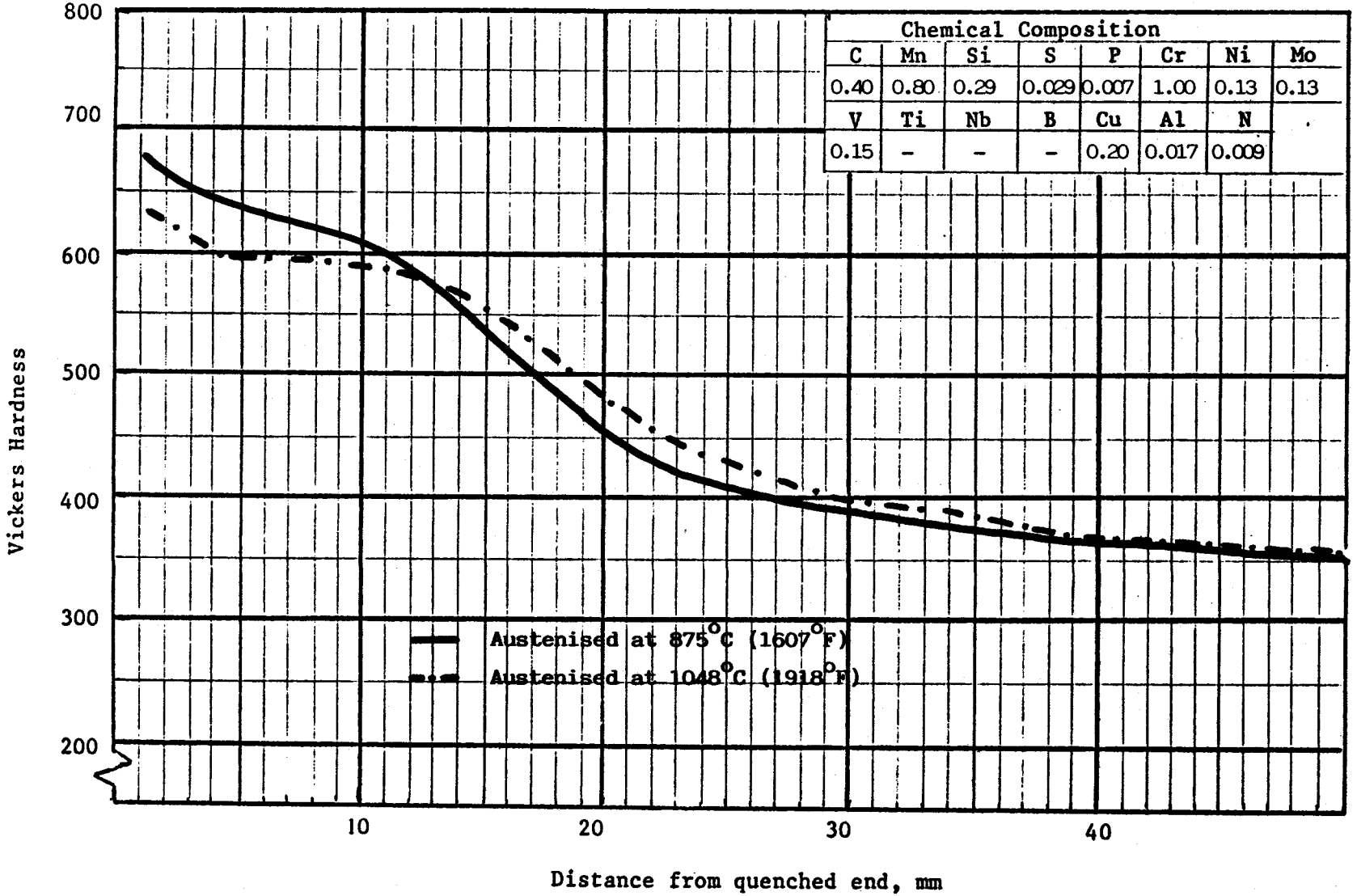
Steel 26



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.40	0.76	0.30	0.029	0.007	0.98	0.13	0.16
V	Ti	Nb	B	Cu	Al	N	
0.05	-	-	-	0.20	0.009	0.008	

Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 56

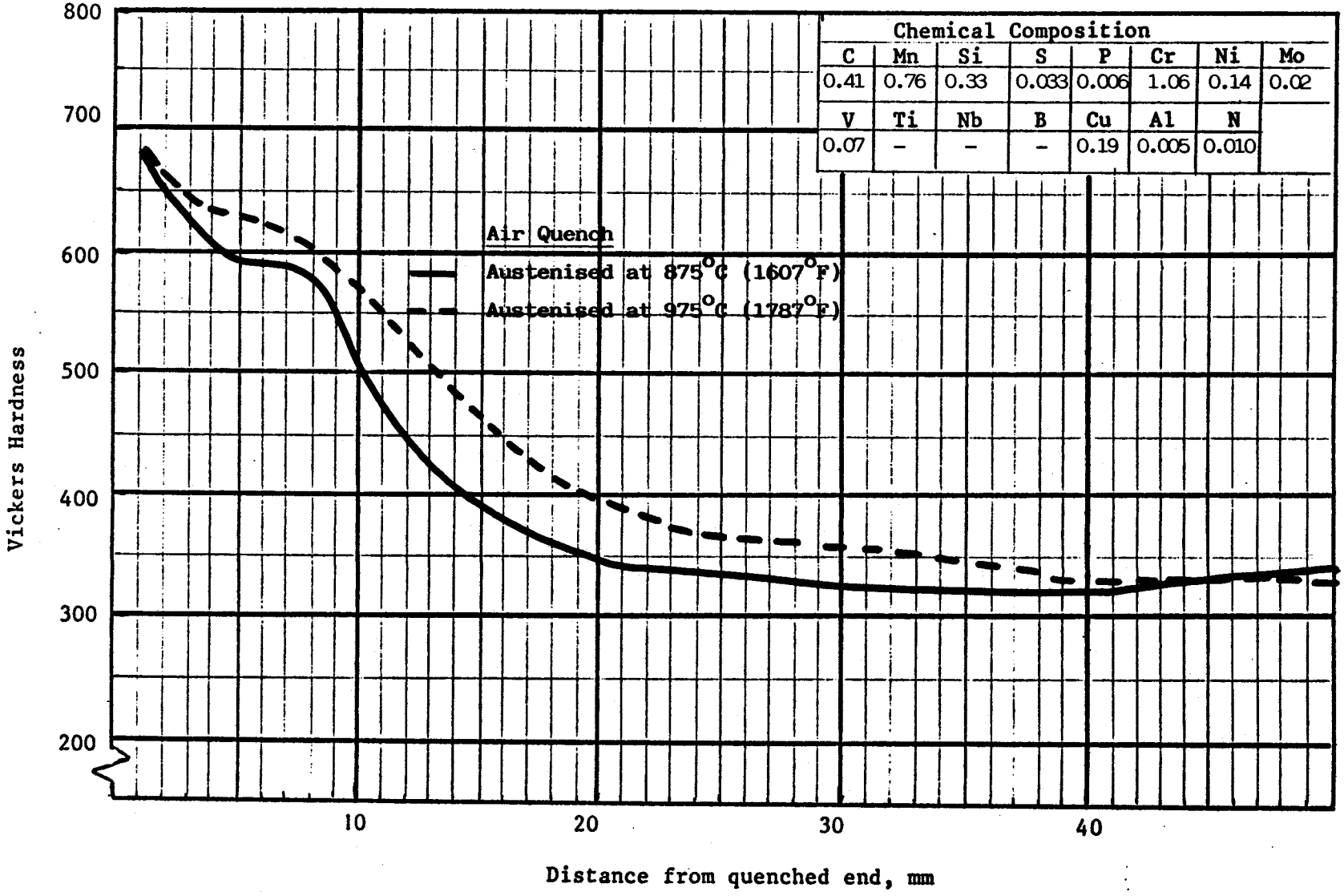
Steel 27



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.40	0.80	0.29	0.029	0.007	1.00	0.13	0.13
V	Ti	Nb	B	Cu	Al	N	
0.15	-	-	-	0.20	0.017	0.009	

Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 54

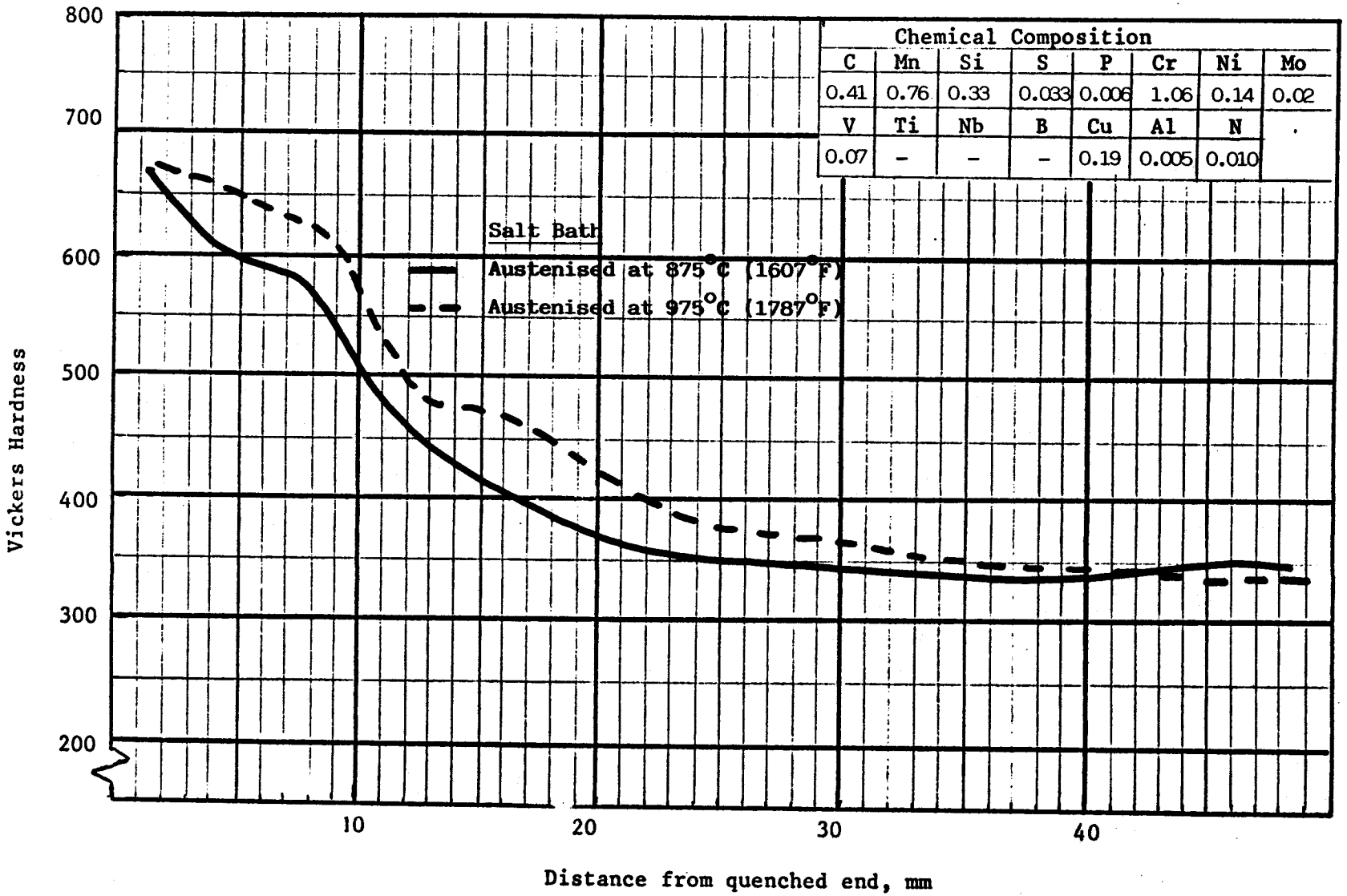
Steel 28a



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.41	0.76	0.33	0.033	0.006	1.06	0.14	0.02
V	Ti	Nb	B	Cu	Al	N	
0.07	–	–	–	0.19	0.005	0.010	

Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 40

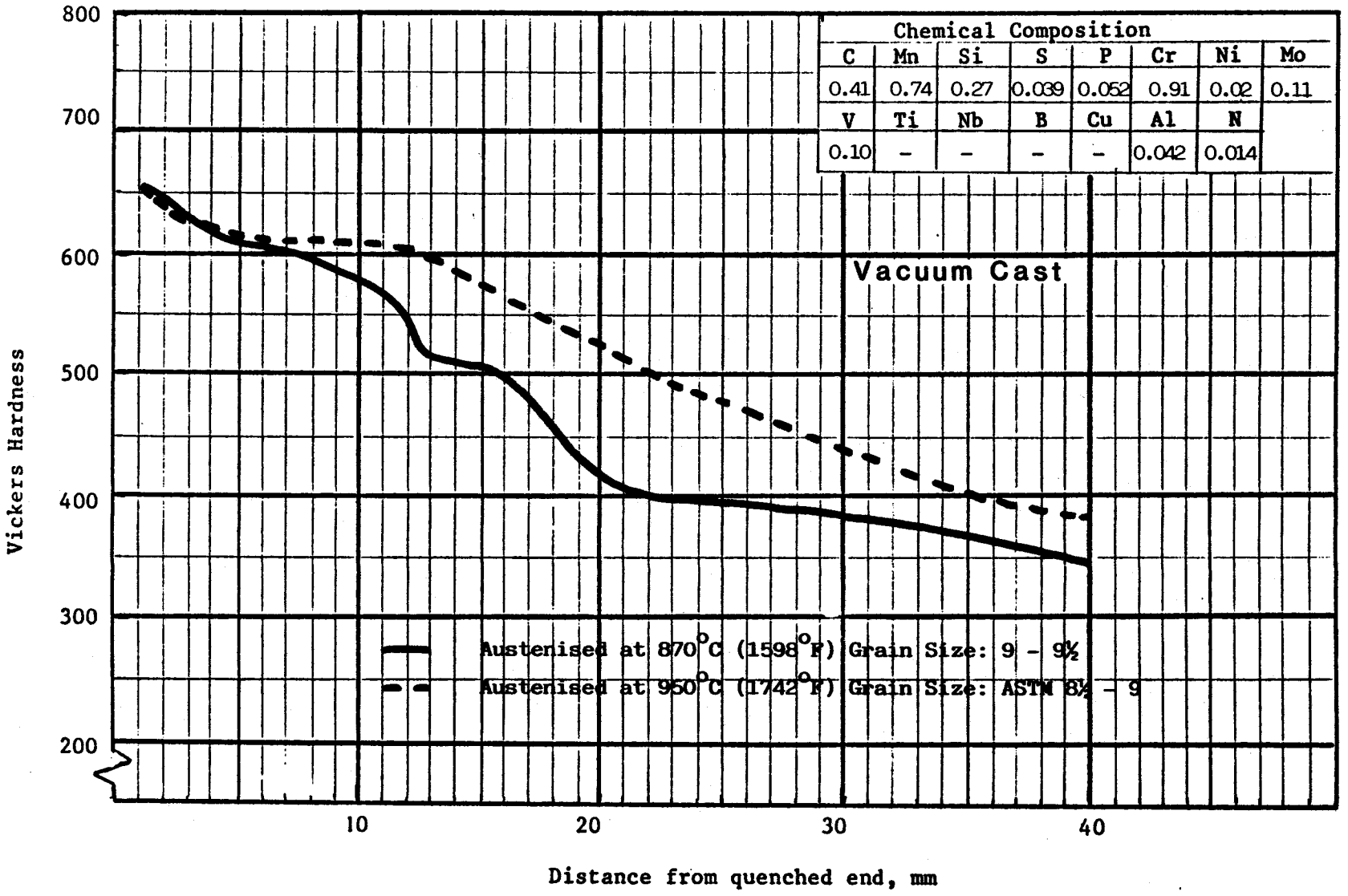
Steel 28b



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.41	0.76	0.33	0.033	0.006	1.06	0.14	0.02
V	Ti	Nb	B	Cu	Al	N	
0.07	-	-	-	0.19	0.005	0.010	

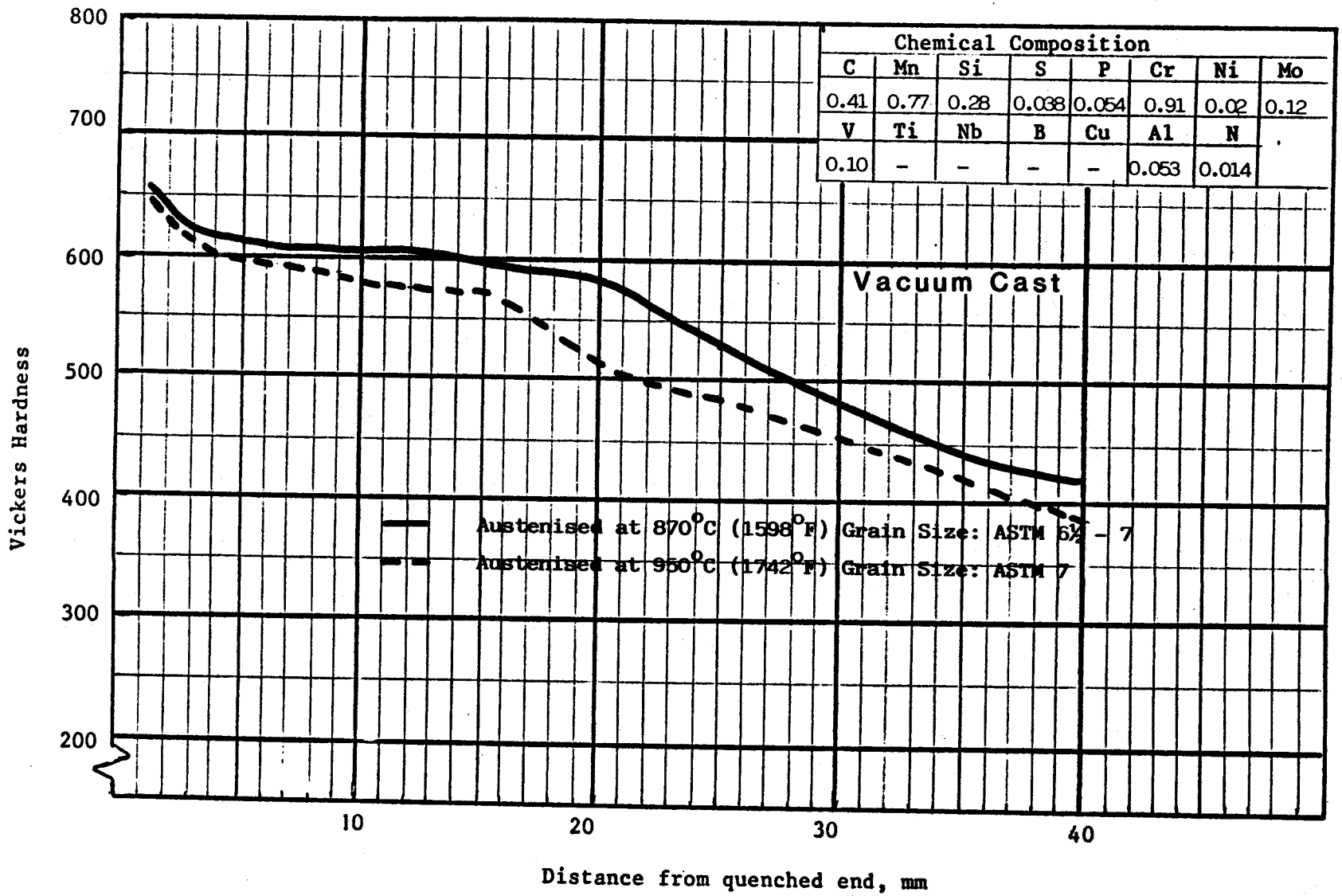
Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 40

Steel 29



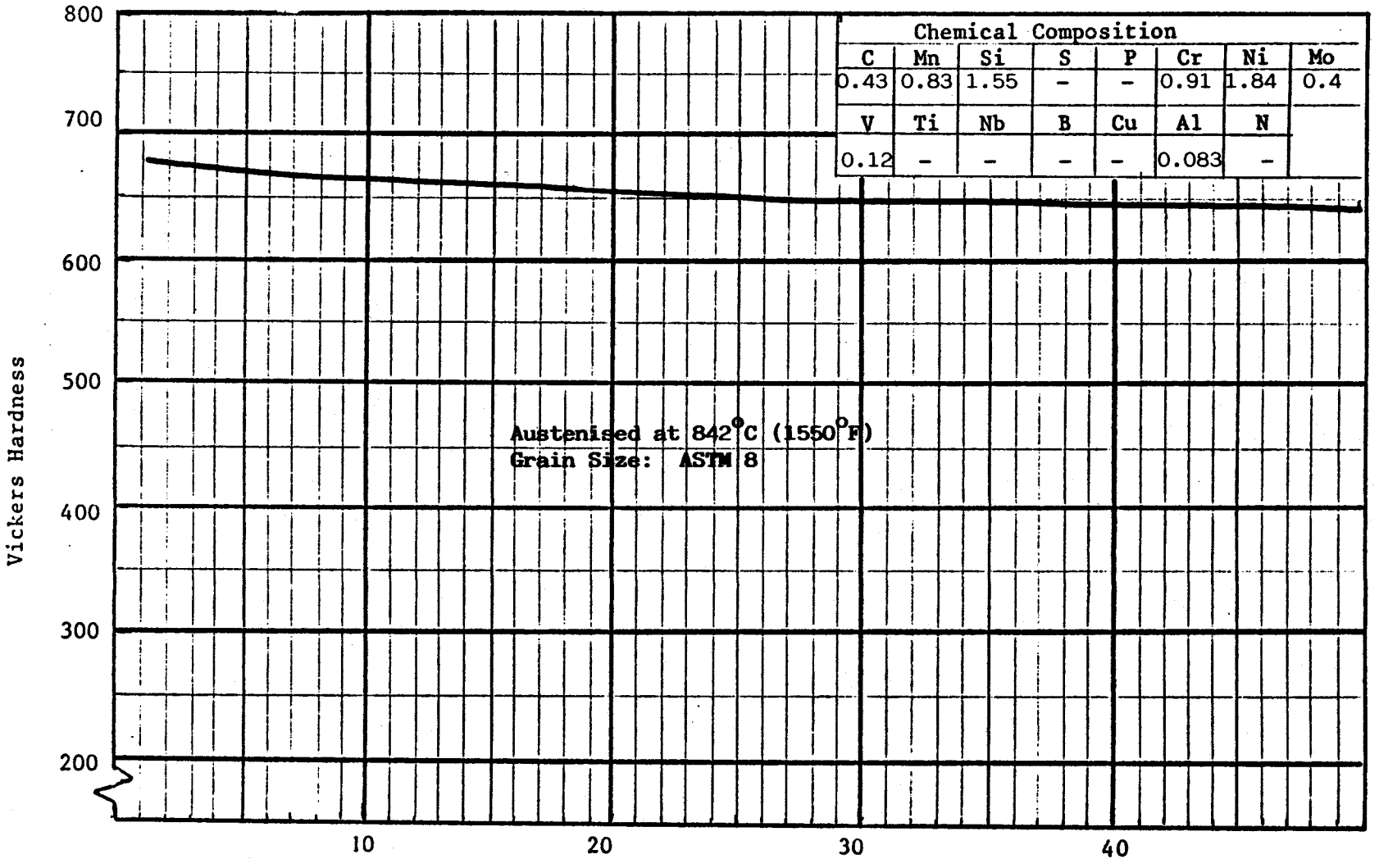
Source: Diagram determined by Sheffield University, England
Van ref: 101

Steel 30



Source: Diagram determined by Sheffield University, England.
Van ref: 102

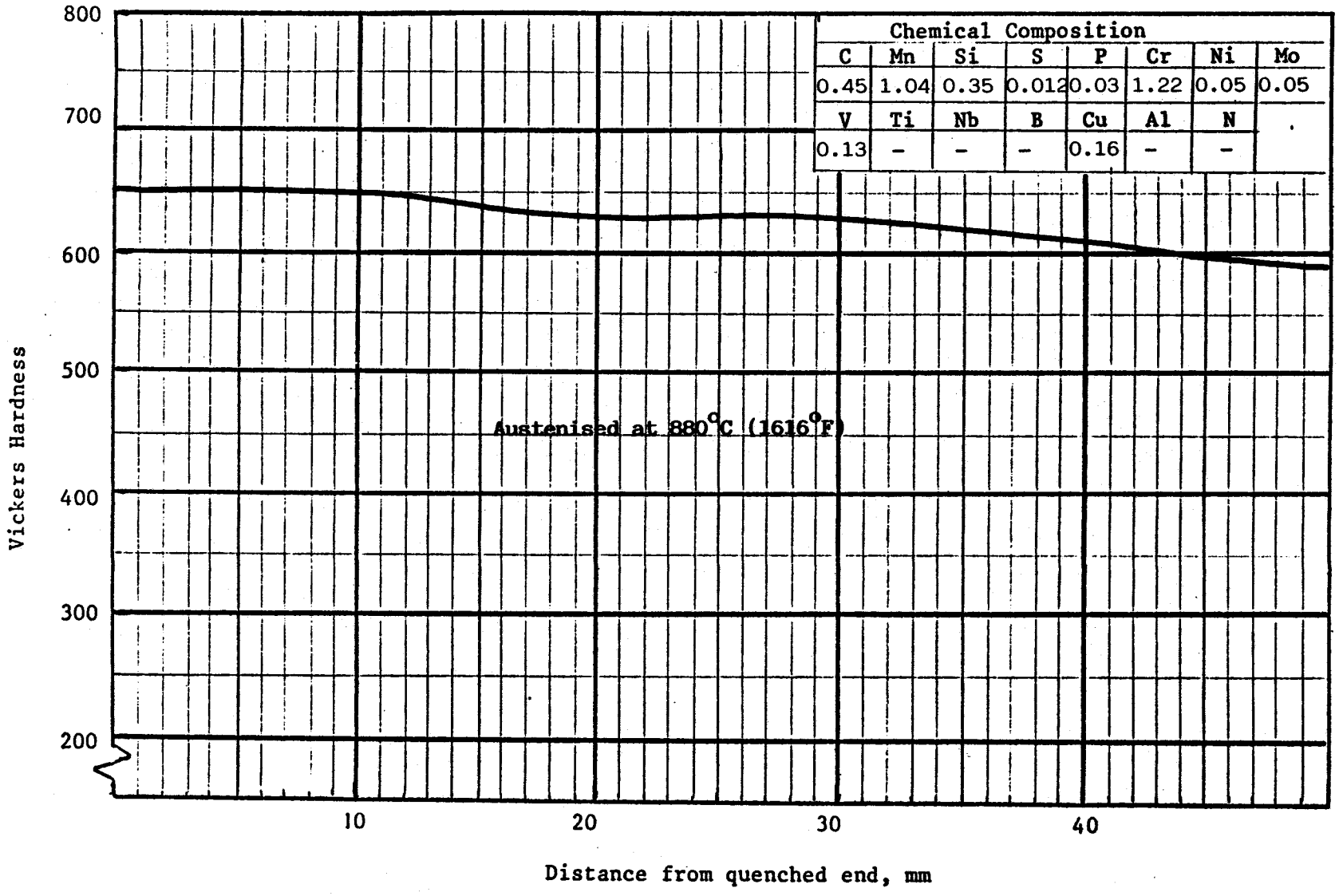
Steel 31



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.43	0.83	1.55	-	-	0.91	1.84	0.4
V	Ti	Nb	B	Cu	Al	N	
0.12	-	-	-	-	0.083	-	

Source: Atlas of Isothermal and Cooling Transformation Diagrams, ASM, 1977
Van ref: 1

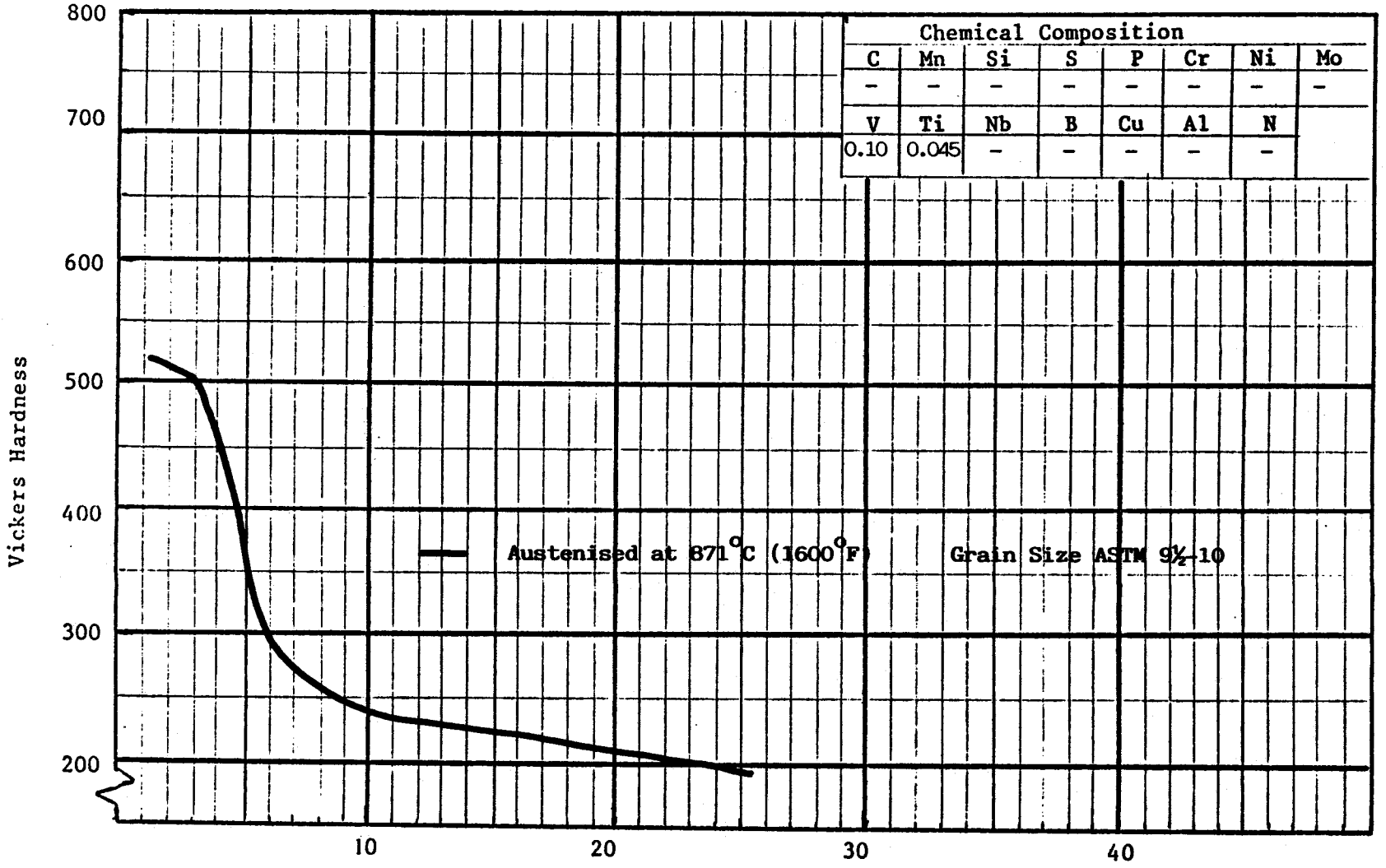
Steel 32



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.45	1.04	0.35	0.012	0.03	1.22	0.05	0.05
V	Ti	Nb	B	Cu	Al	N	
0.13	-	-	-	0.16	-	-	

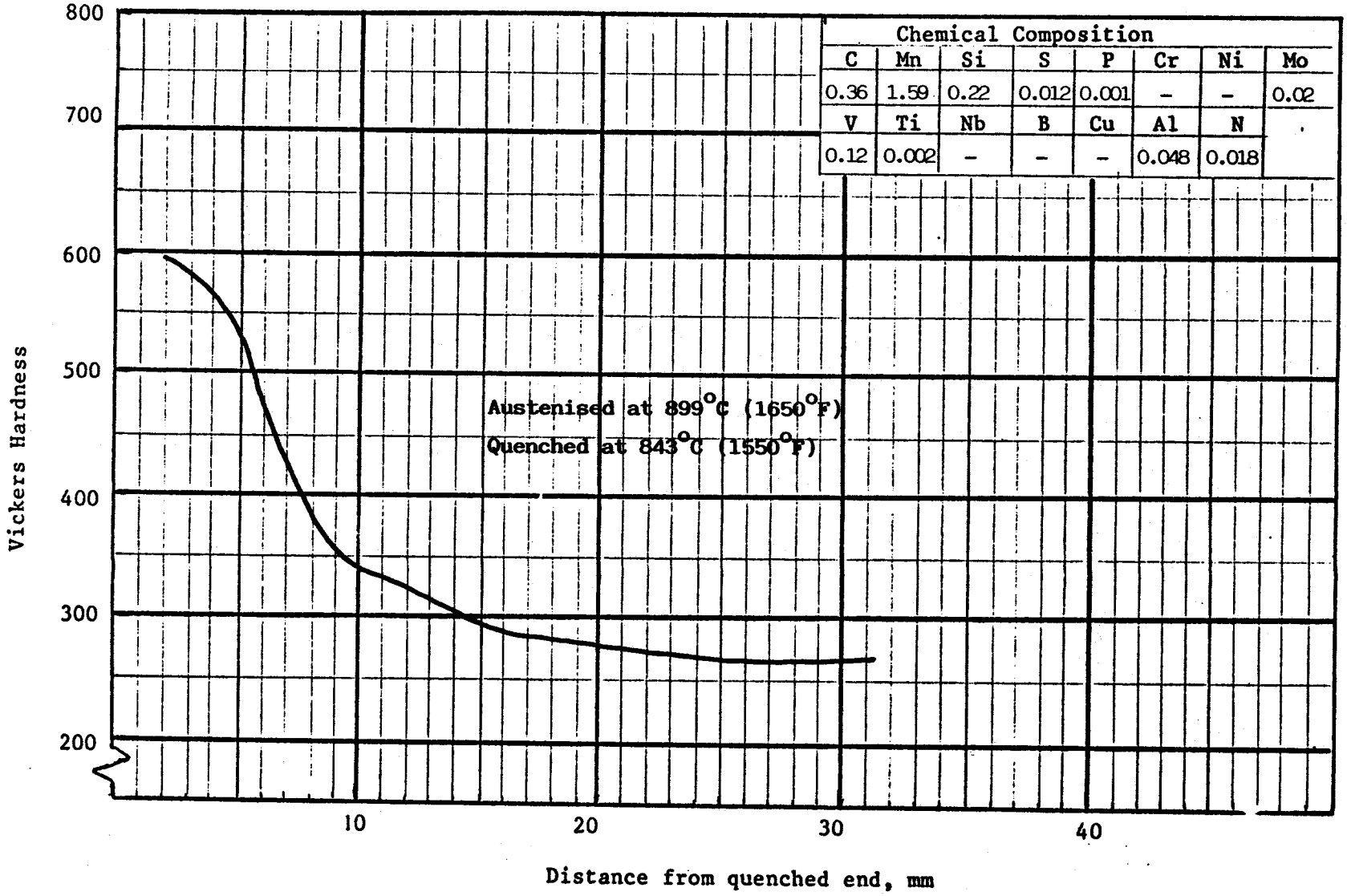
Source: Atlas zur Warmbehandlung der Stahle, Max Planck Institut fur Eisenforschung, 1958
Van ref: 4

Steel 33



Source: Diagram determined by Foote Mineral Company, USA.
Van ref: 33

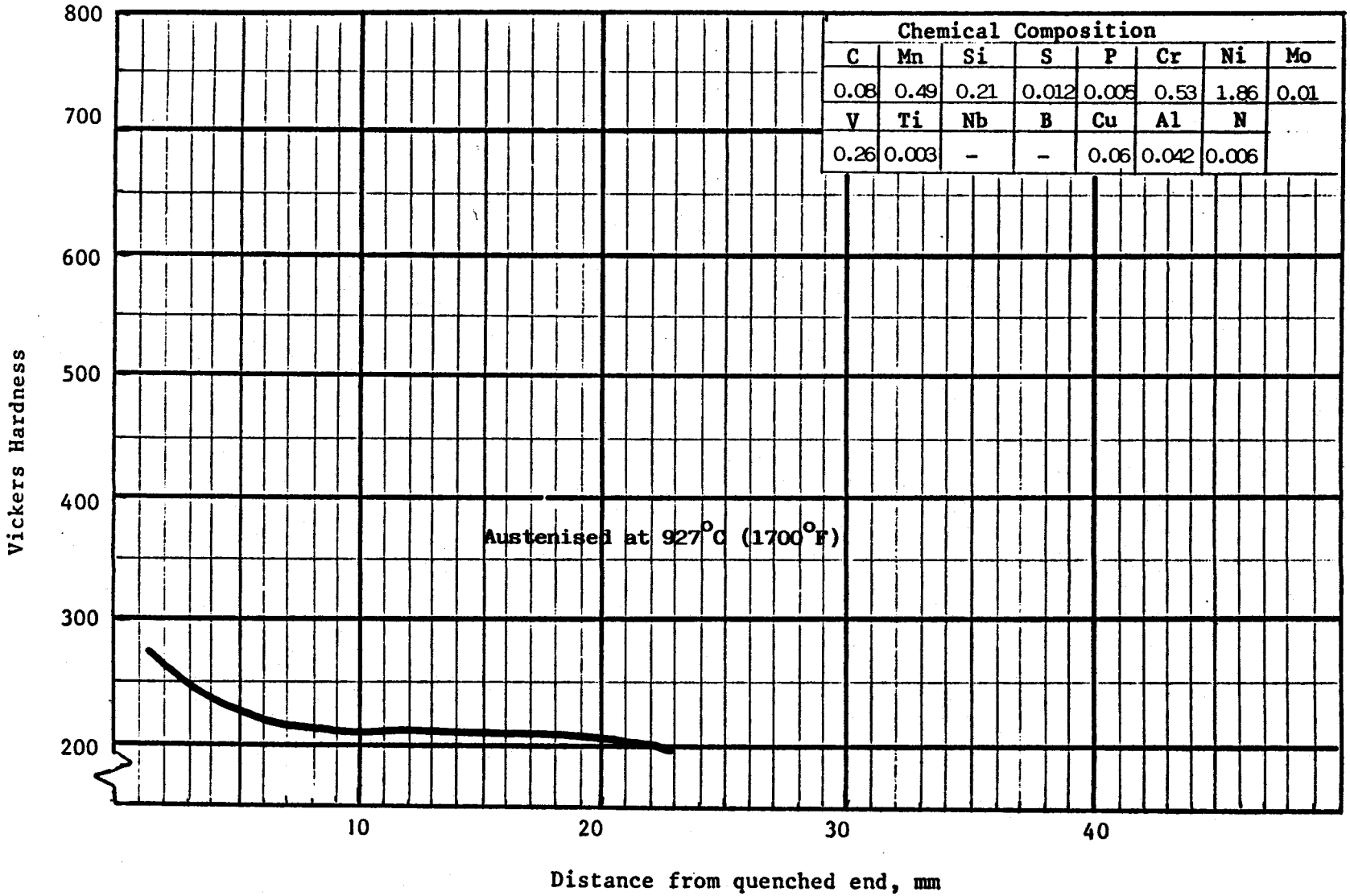
Steel 34



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.36	1.59	0.22	0.012	0.001	–	–	0.02
V	Ti	Nb	B	Cu	Al	N	
0.12	0.002	–	–	–	0.048	0.018	

Source: Foote Mineral Company, U.S.A.
Van ref: 60

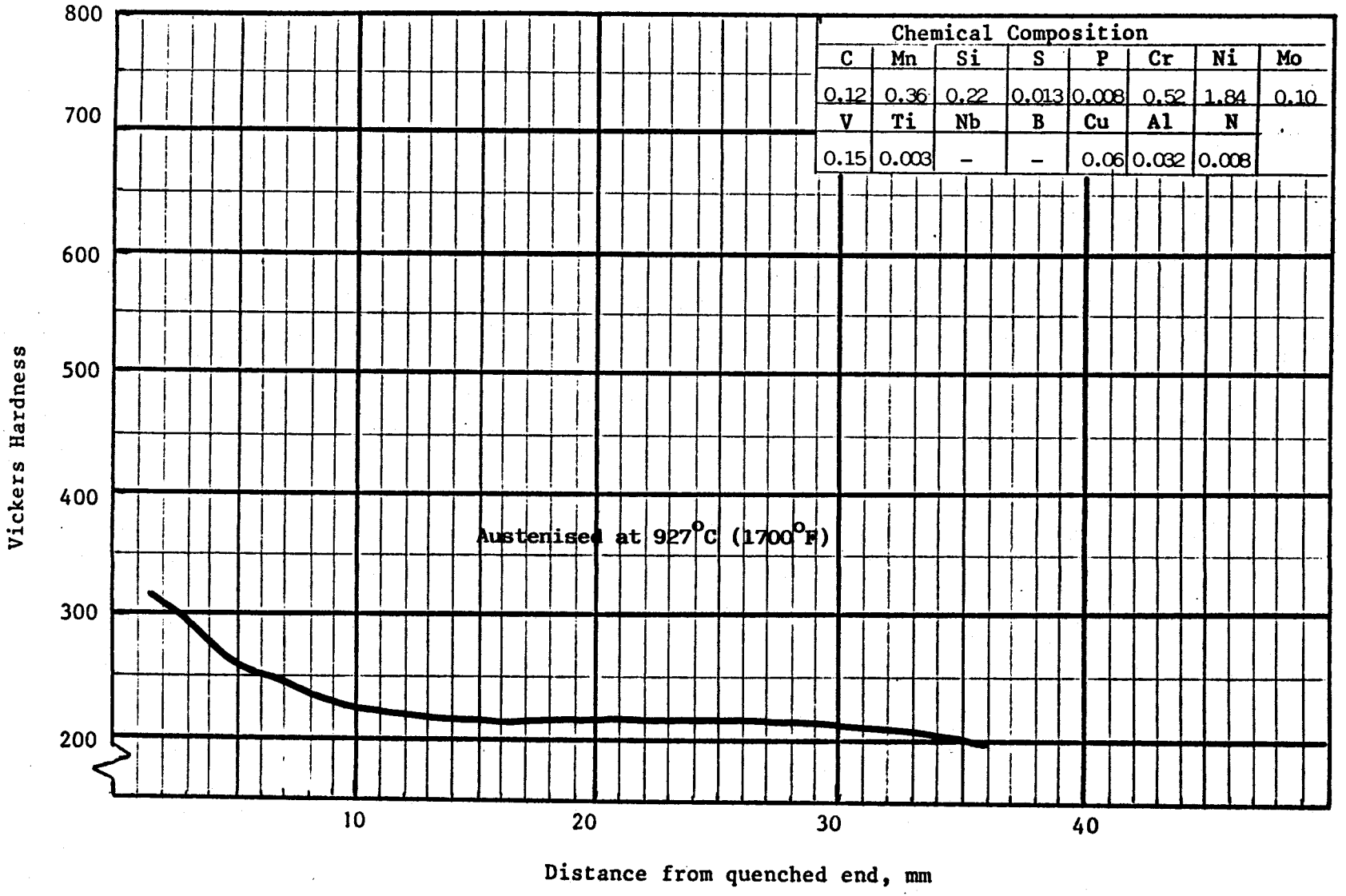
Steel 35



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.08	0.49	0.21	0.012	0.005	0.53	1.86	0.01
V	Ti	Nb	B	Cu	Al	N	
0.26	0.003	-	-	0.06	0.042	0.006	

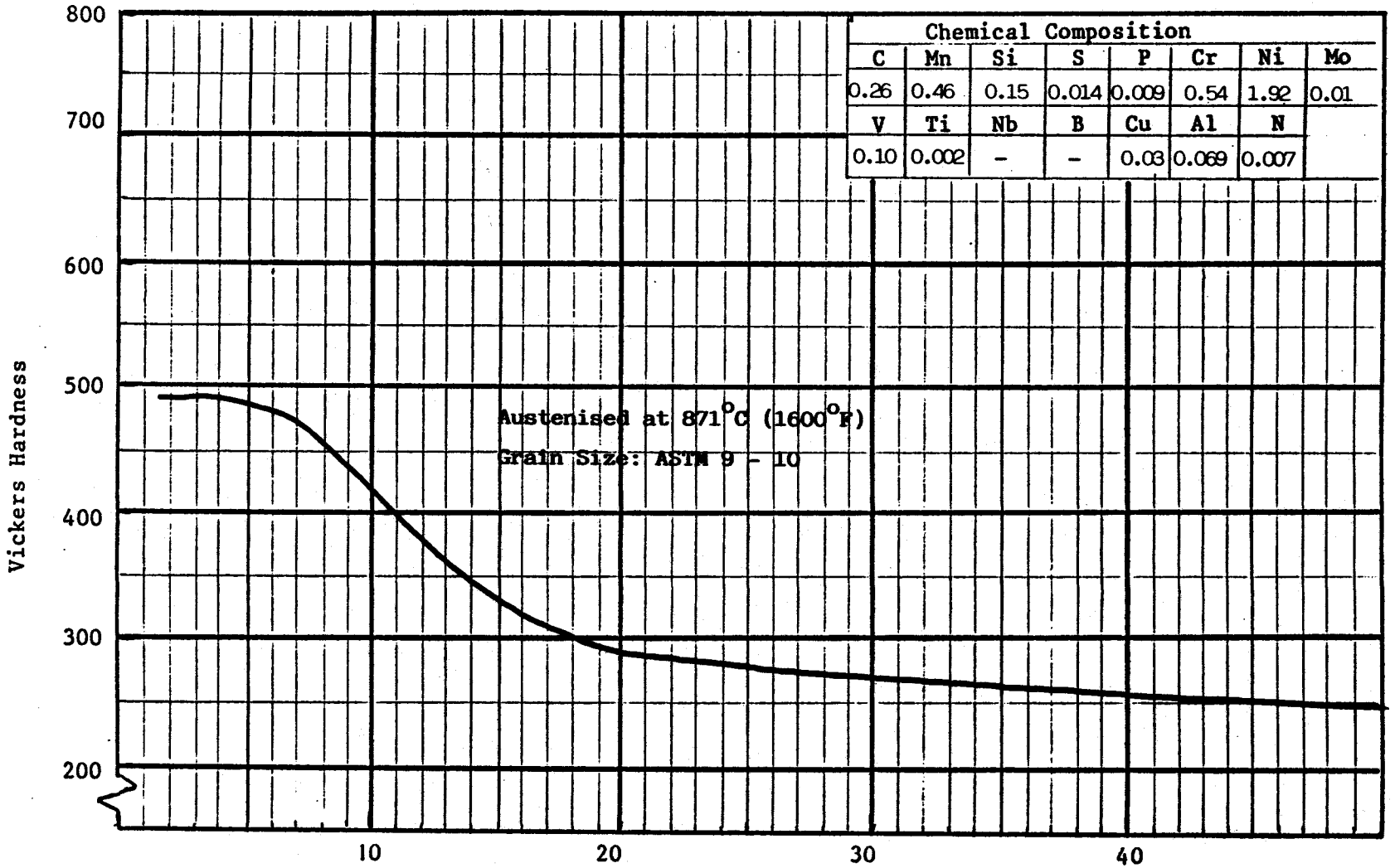
Source: Foote Mineral Company, U.S.A.
Van ref: 74

Steel 36



Source: Foote Mineral Company, U.S.A.
Van ref: 75

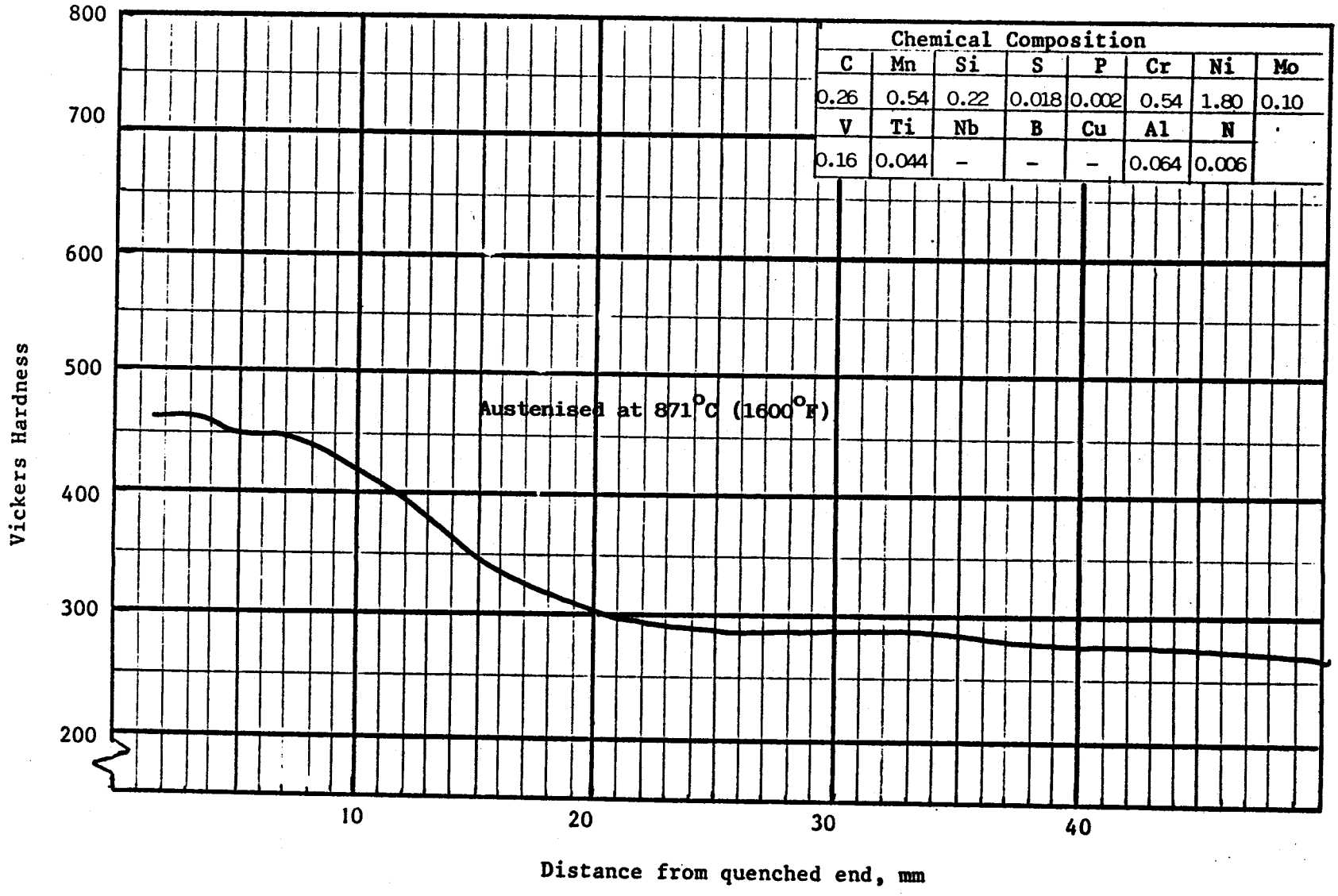
Steel 37



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.26	0.46	0.15	0.014	0.009	0.54	1.92	0.01
V	Ti	Nb	B	Cu	Al	N	
0.10	0.002	-	-	0.03	0.069	0.007	

Source: Foote Mineral Company, U.S.A.
Van ref: 69

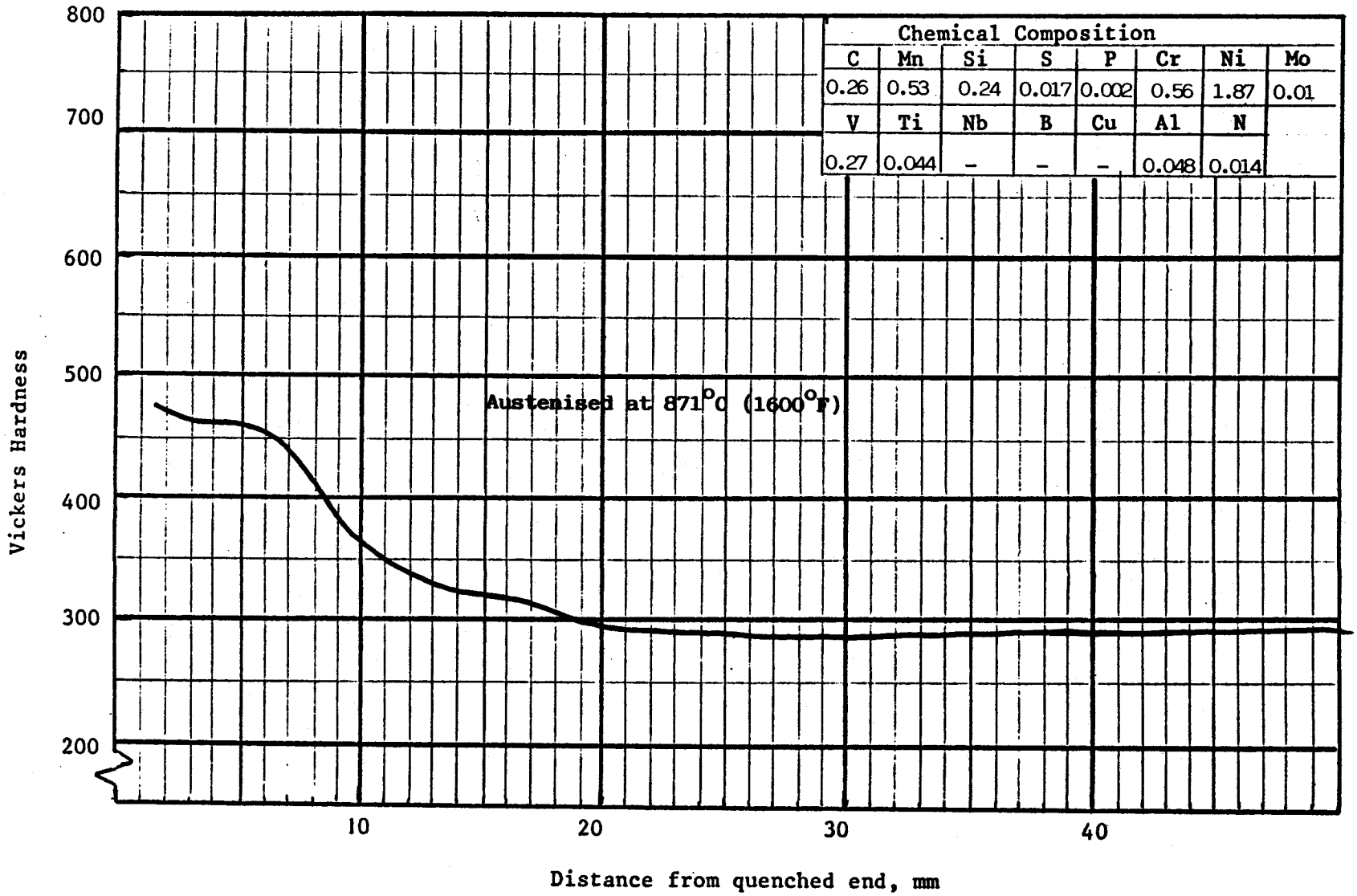
Steel 38



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.26	0.54	0.22	0.018	0.002	0.54	1.80	0.10
V	Ti	Nb	B	Cu	Al	N	
0.16	0.044	–	–	–	0.064	0.006	

Source: Foote Mineral Company, U.S.A.
Van ref: 71

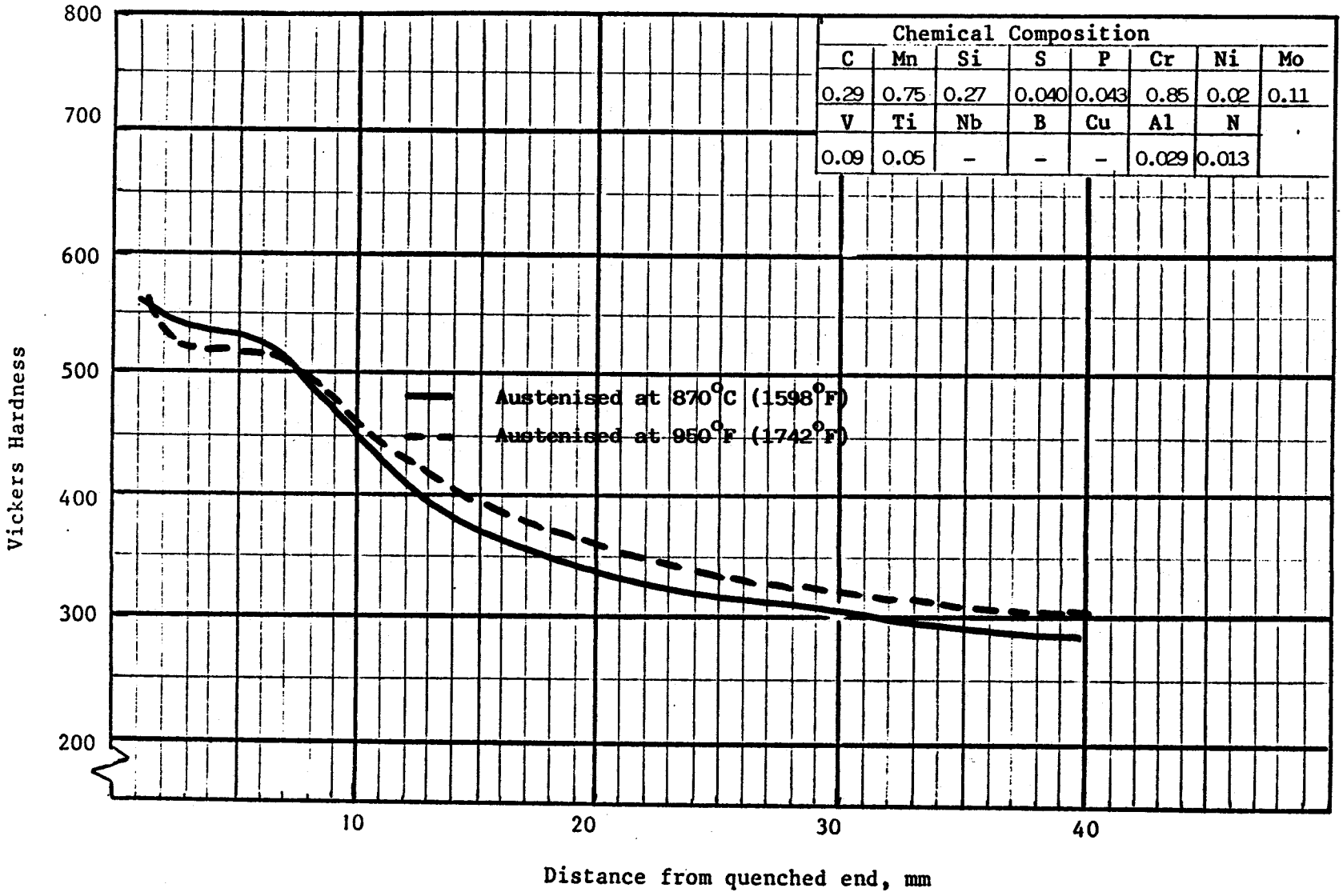
Steel 39



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.26	0.53	0.24	0.017	0.002	0.56	1.87	0.01
V	Ti	Nb	B	Cu	Al	N	
0.27	0.044	–	–	–	0.048	0.014	

Source: Foote Mineral Company, U.S.A.
Van ref: 70

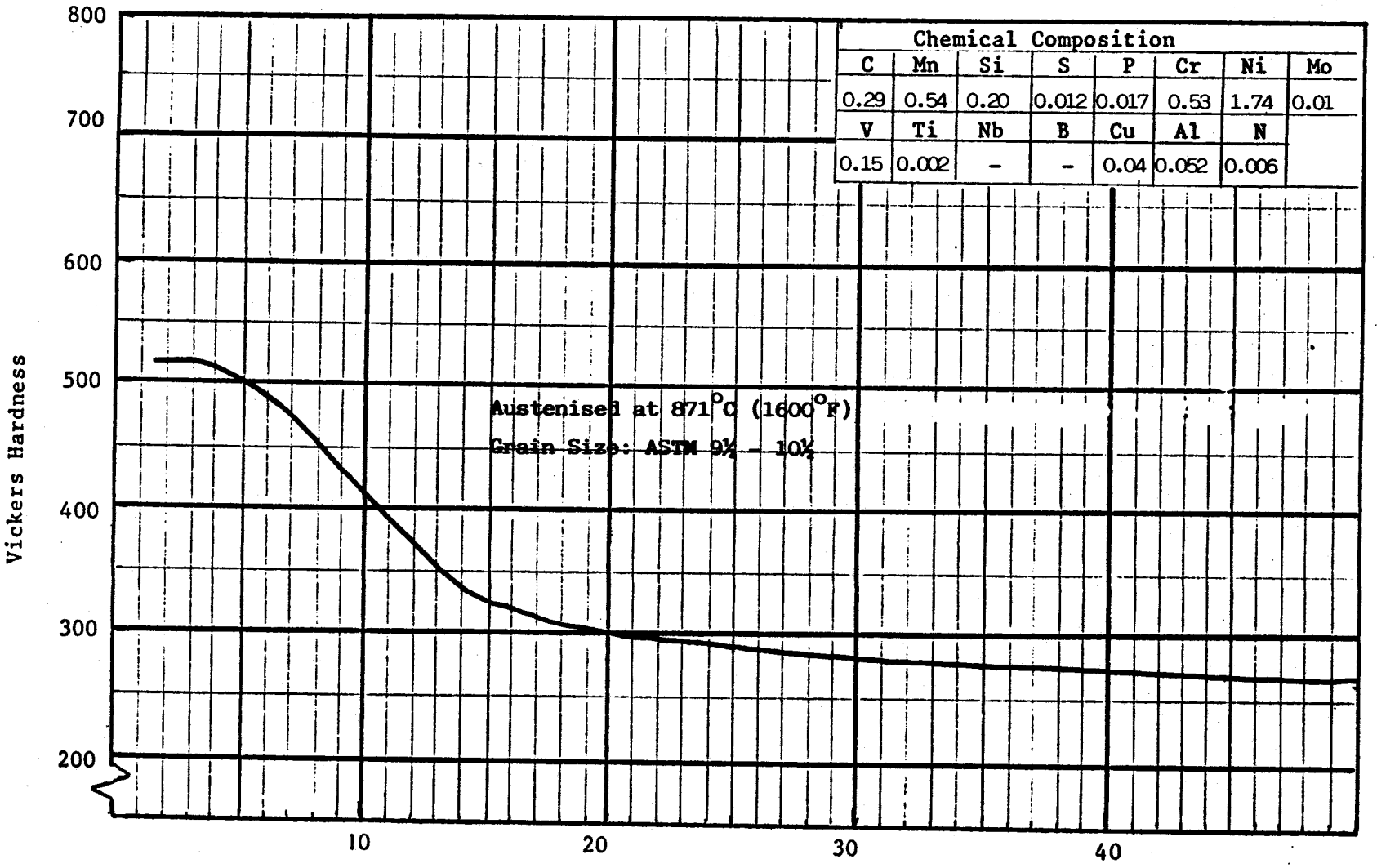
Steel 40



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.29	0.75	0.27	0.040	0.043	0.85	0.02	0.11
V	Ti	Nb	B	Cu	Al	N	
0.09	0.05	–	–	–	0.029	0.013	

Source: Diagram determined by Sheffield University, England
Van ref: 22

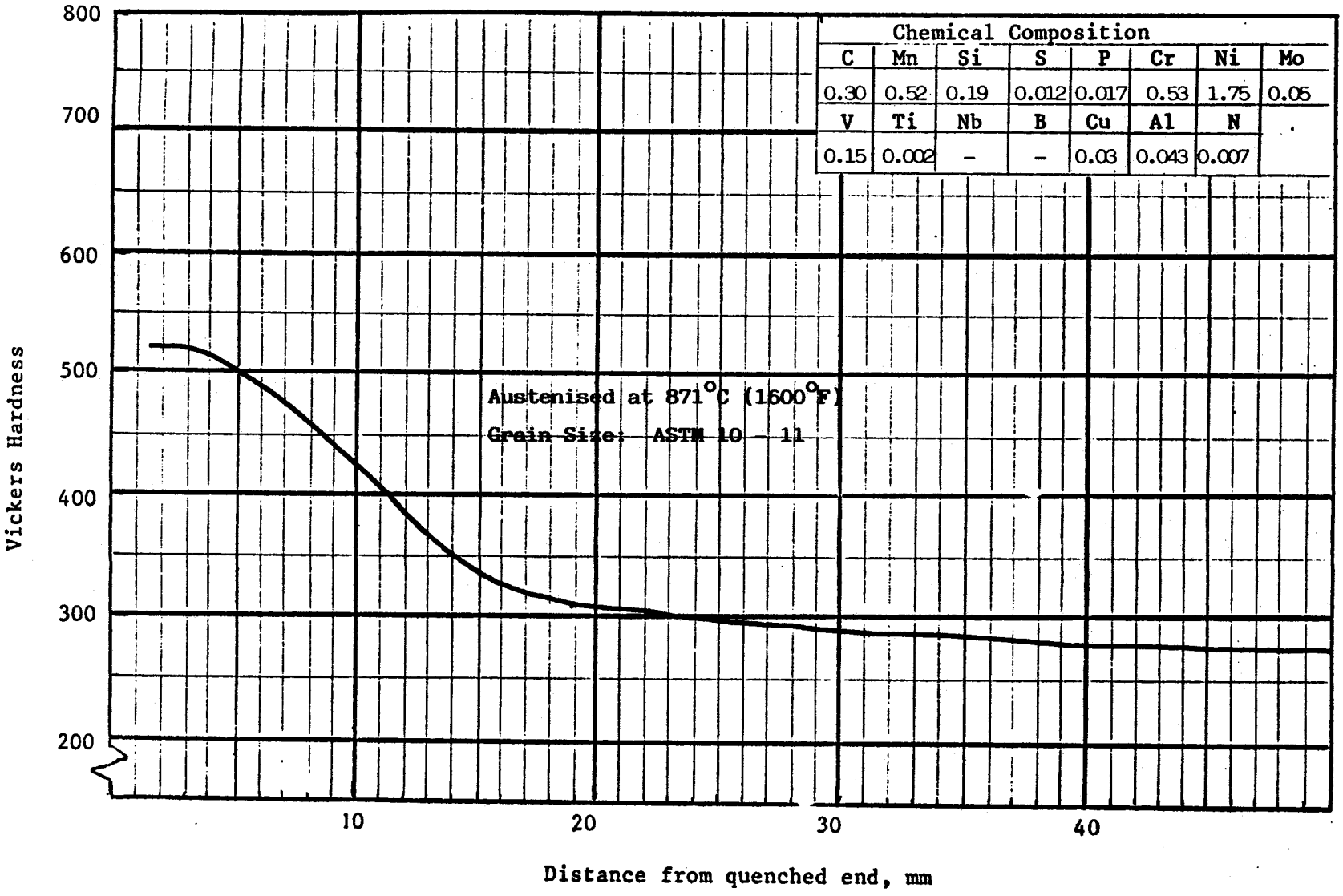
Steel 41



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.29	0.54	0.20	0.012	0.017	0.53	1.74	0.01
V	Ti	Nb	B	Cu	Al	N	
0.15	0.002	-	-	0.04	0.052	0.006	

Source: Foote Mineral Company, U.S.A.
Van ref: 64

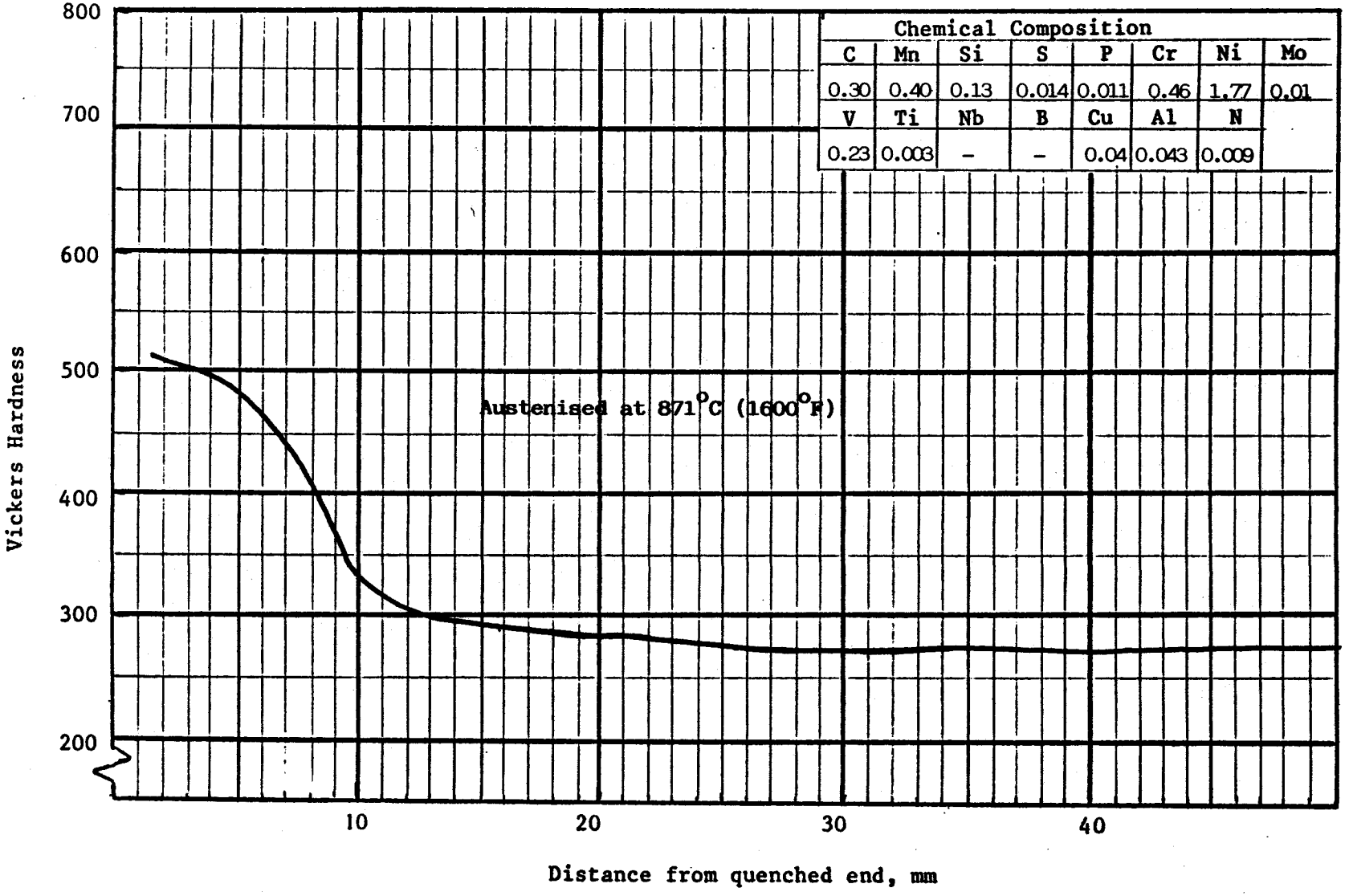
Steel 42



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.30	0.52	0.19	0.012	0.017	0.53	1.75	0.05
V	Ti	Nb	B	Cu	Al	N	
0.15	0.002	–	–	0.03	0.043	0.007	

Source: Foote Mineral Company, U.S.A.
Van ref: 65

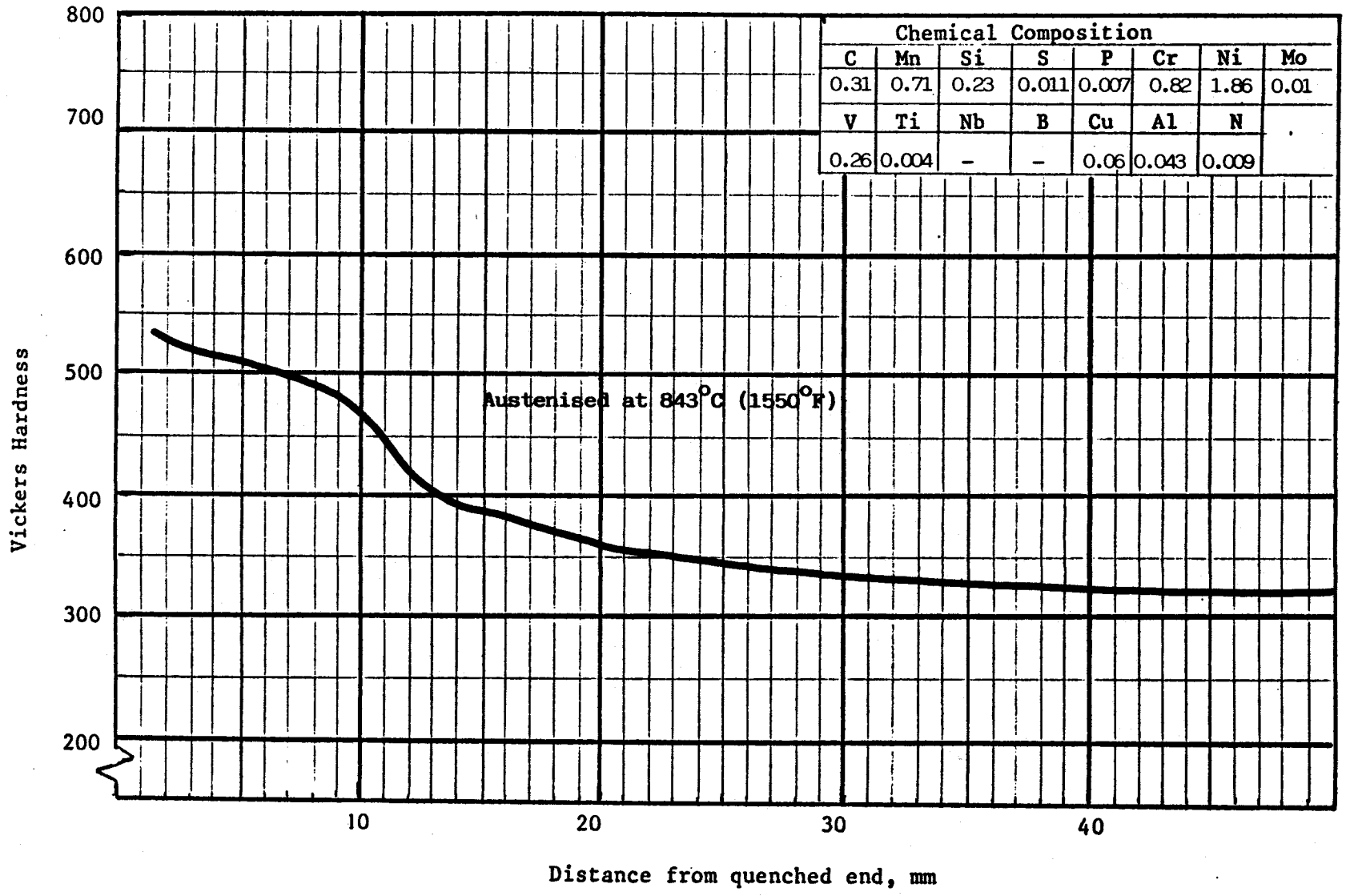
Steel 43



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.30	0.40	0.13	0.014	0.011	0.46	1.77	0.01
V	Ti	Nb	B	Cu	Al	N	
0.23	0.003	–	–	0.04	0.043	0.009	

Source: Foote Mineral Company, U.S.A.
Van ref: 72

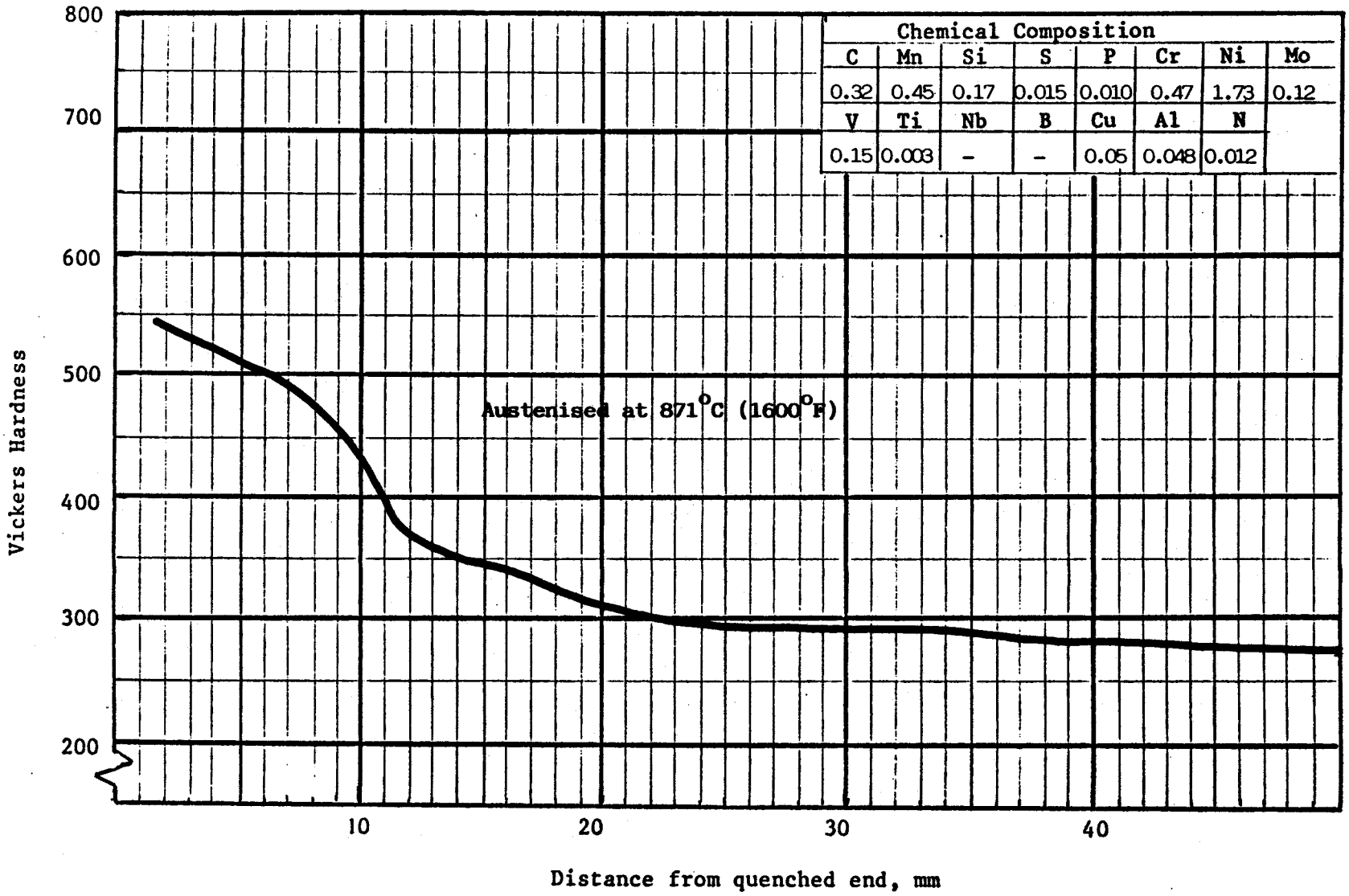
Steel 44



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.31	0.71	0.23	0.011	0.007	0.82	1.86	0.01
V	Ti	Nb	B	Cu	Al	N	
0.26	0.004	–	–	0.06	0.043	0.009	

Source: Foote Mineral Company, U.S.A.
Van ref: 76

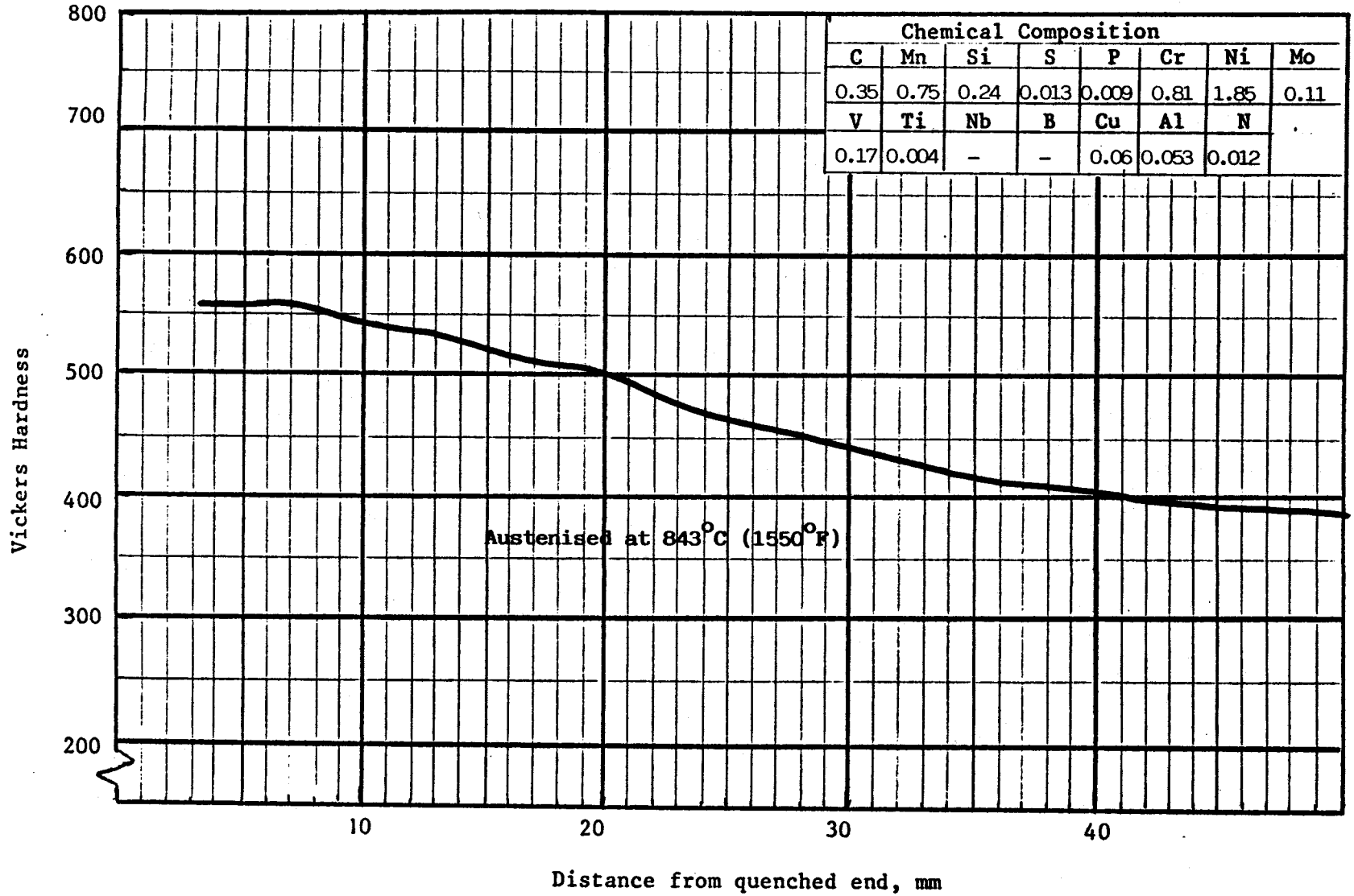
Steel 45



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.32	0.45	0.17	0.015	0.010	0.47	1.73	0.12
V	Ti	Nb	B	Cu	Al	N	
0.15	0.003	-	-	0.05	0.048	0.012	

Source: Foote Mineral Company, U.S.A.
Van ref: 73

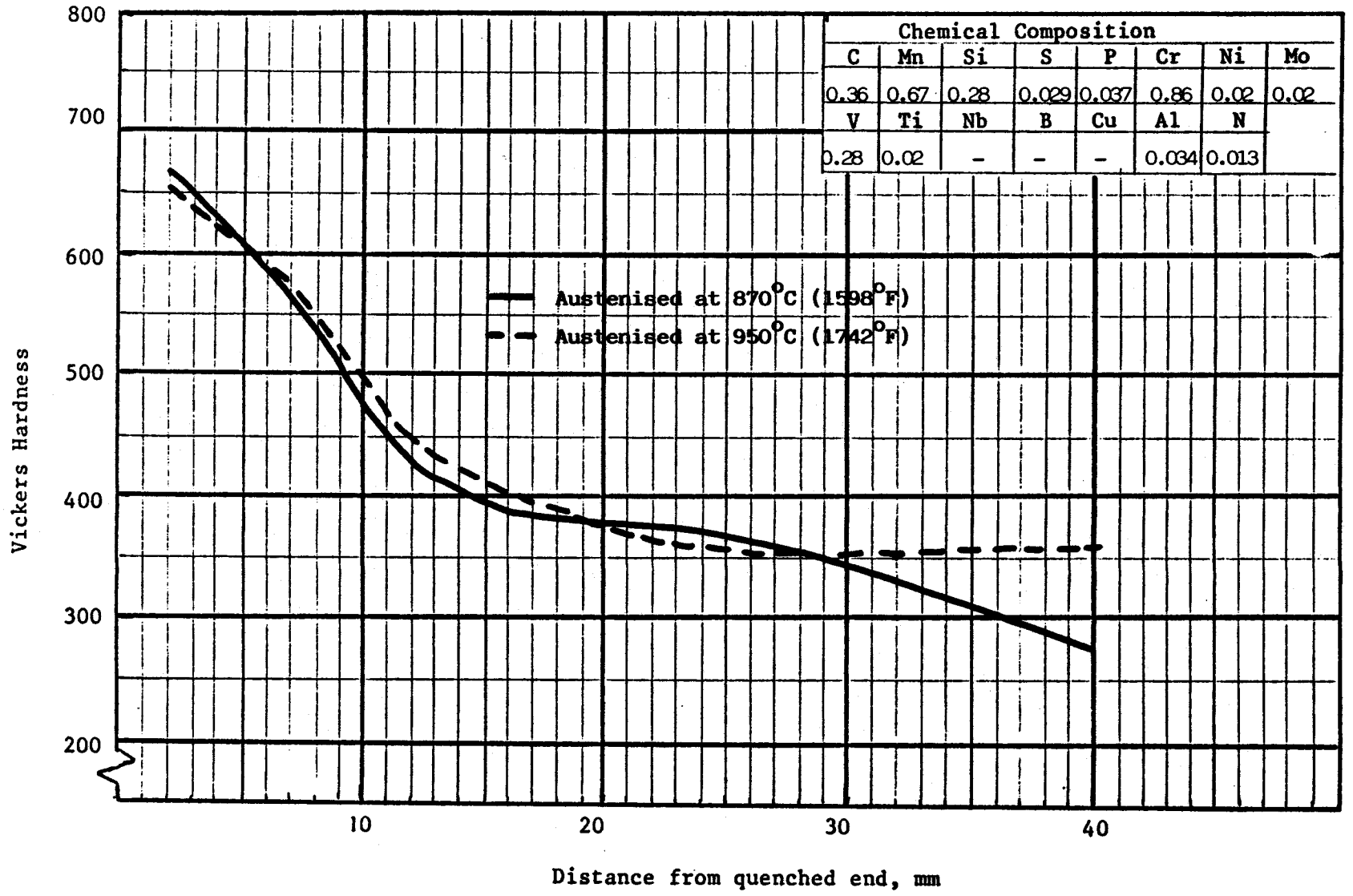
Steel 46



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.35	0.75	0.24	0.013	0.009	0.81	1.85	0.11
V	Ti	Nb	B	Cu	Al	N	
0.17	0.004	–	–	0.06	0.053	0.012	

Source: Foote Mineral Company, U.S.A.
Van ref: 77

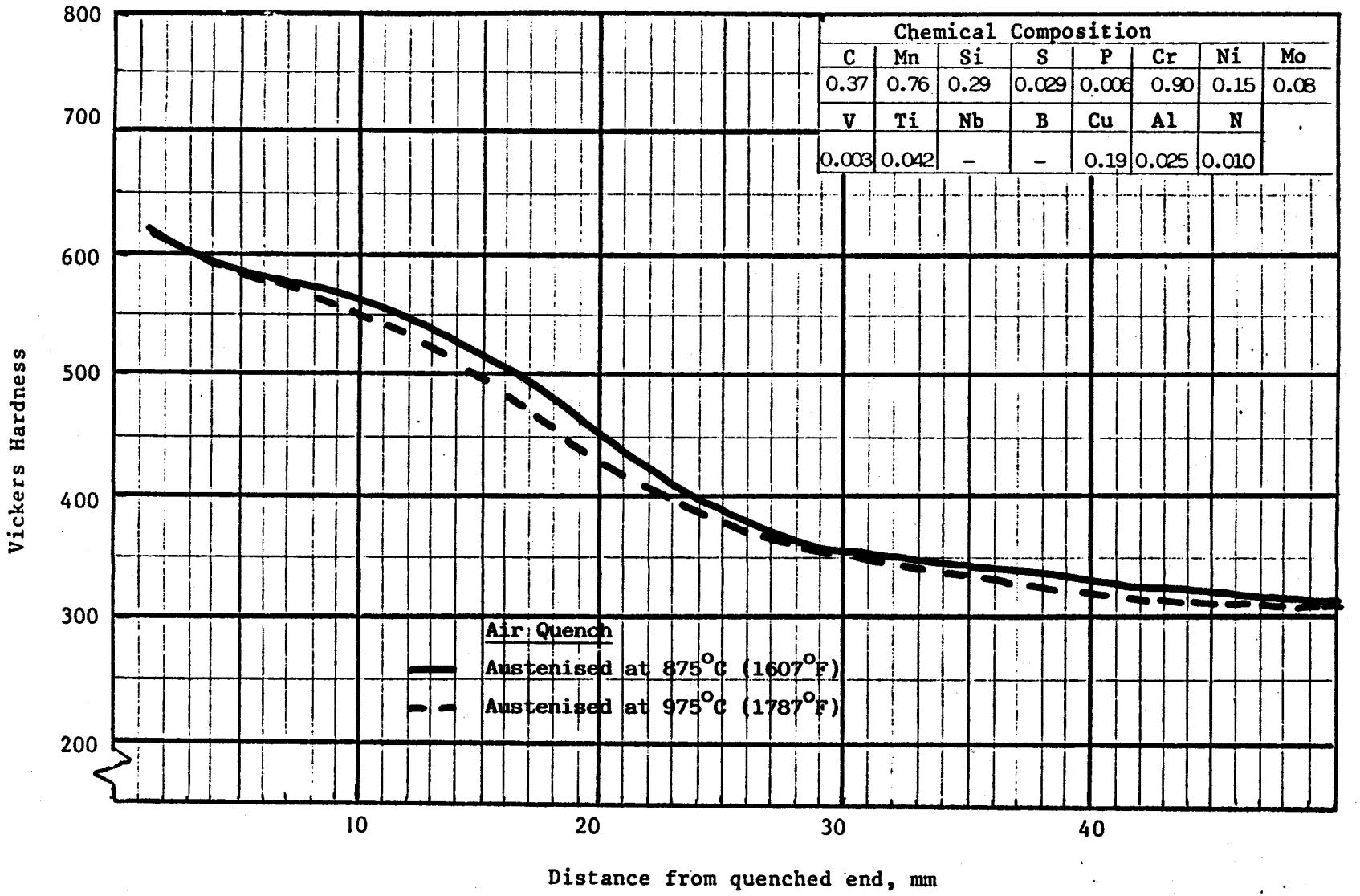
Steel 47



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.36	0.67	0.28	0.029	0.037	0.86	0.02	0.02
V	Ti	Nb	B	Cu	Al	N	
0.28	0.02	-	-	-	0.034	0.013	

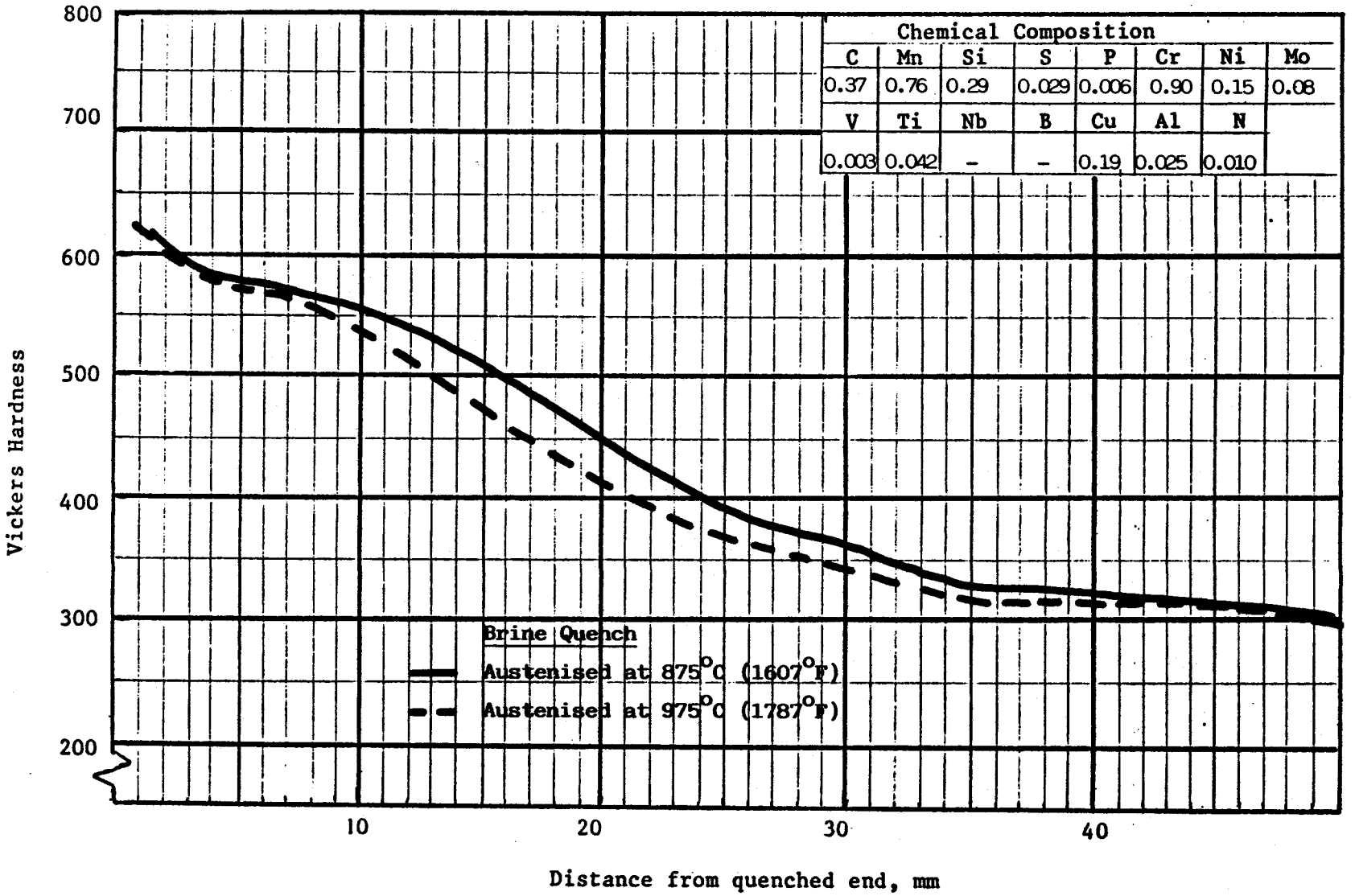
Source: Diagram determined by Sheffield University, England
Van ref: 13

Steel 48a



Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 49

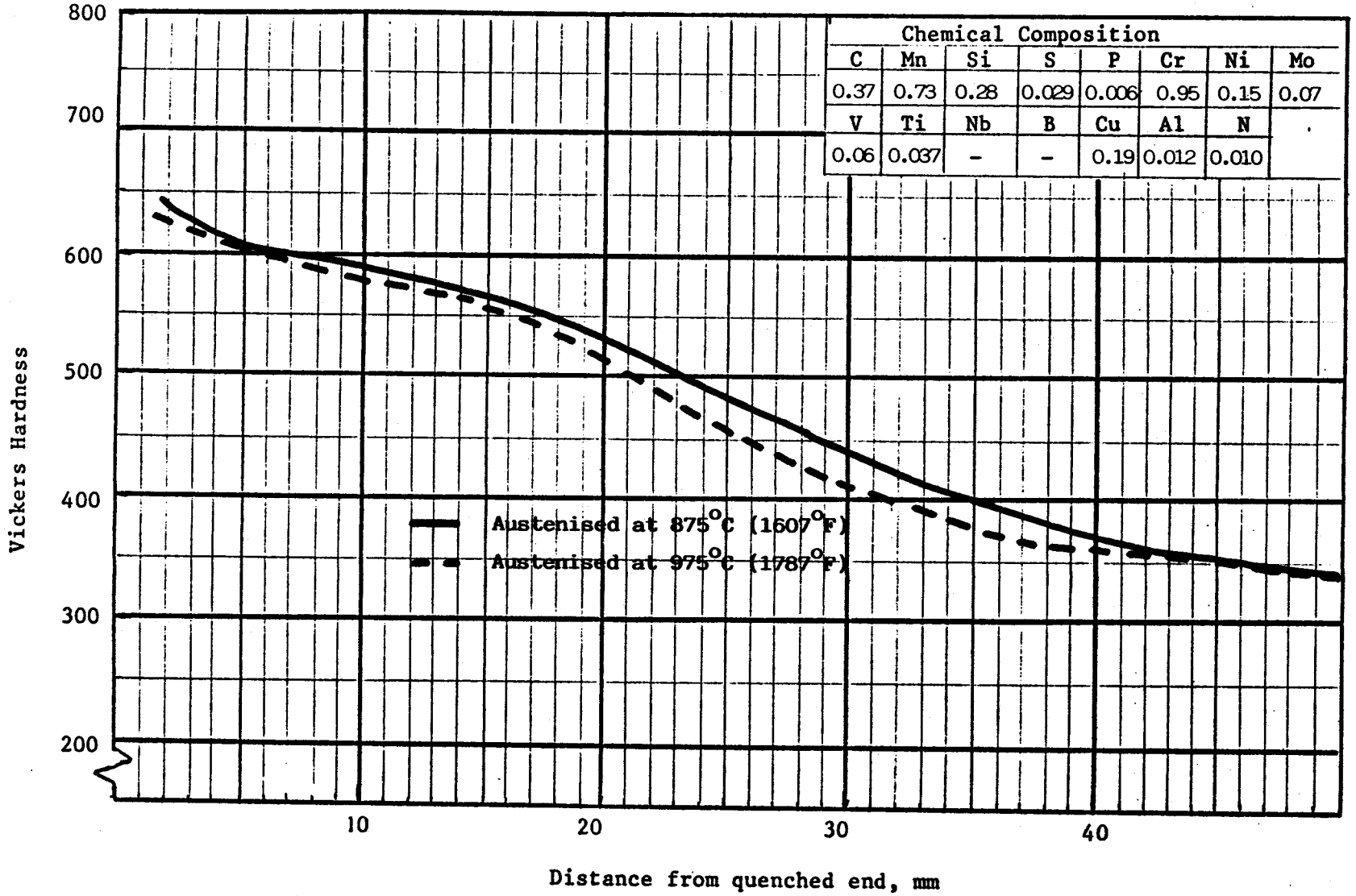
Steel 48b



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.37	0.76	0.29	0.029	0.006	0.90	0.15	0.08
V	Ti	Nb	B	Cu	Al	N	
0.003	0.042	-	-	0.19	0.025	0.010	

Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 49

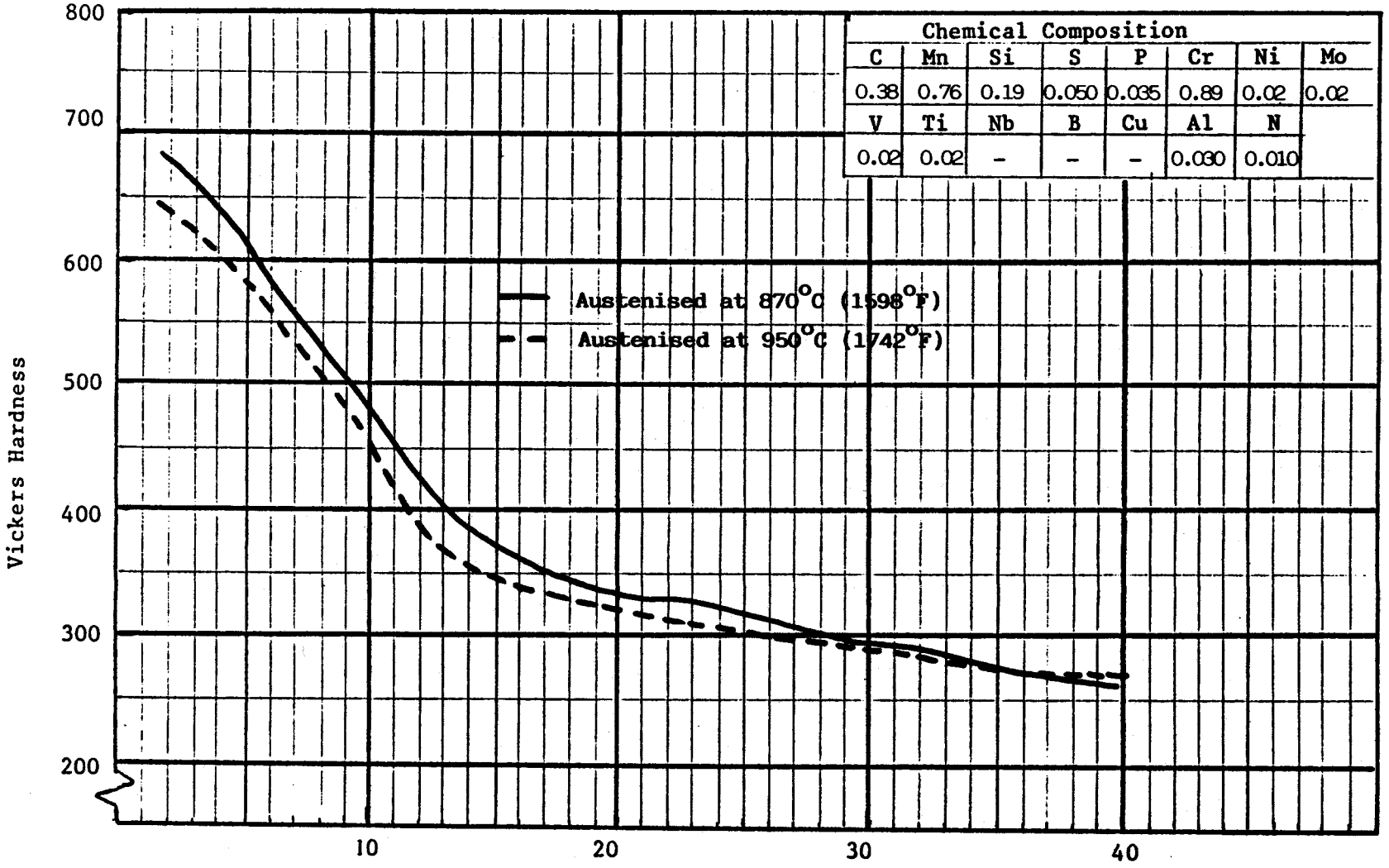
Steel 49



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.37	0.73	0.28	0.029	0.006	0.95	0.15	0.07
V	Ti	Nb	B	Cu	Al	N	
0.06	0.037	-	-	0.19	0.012	0.010	

Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 46

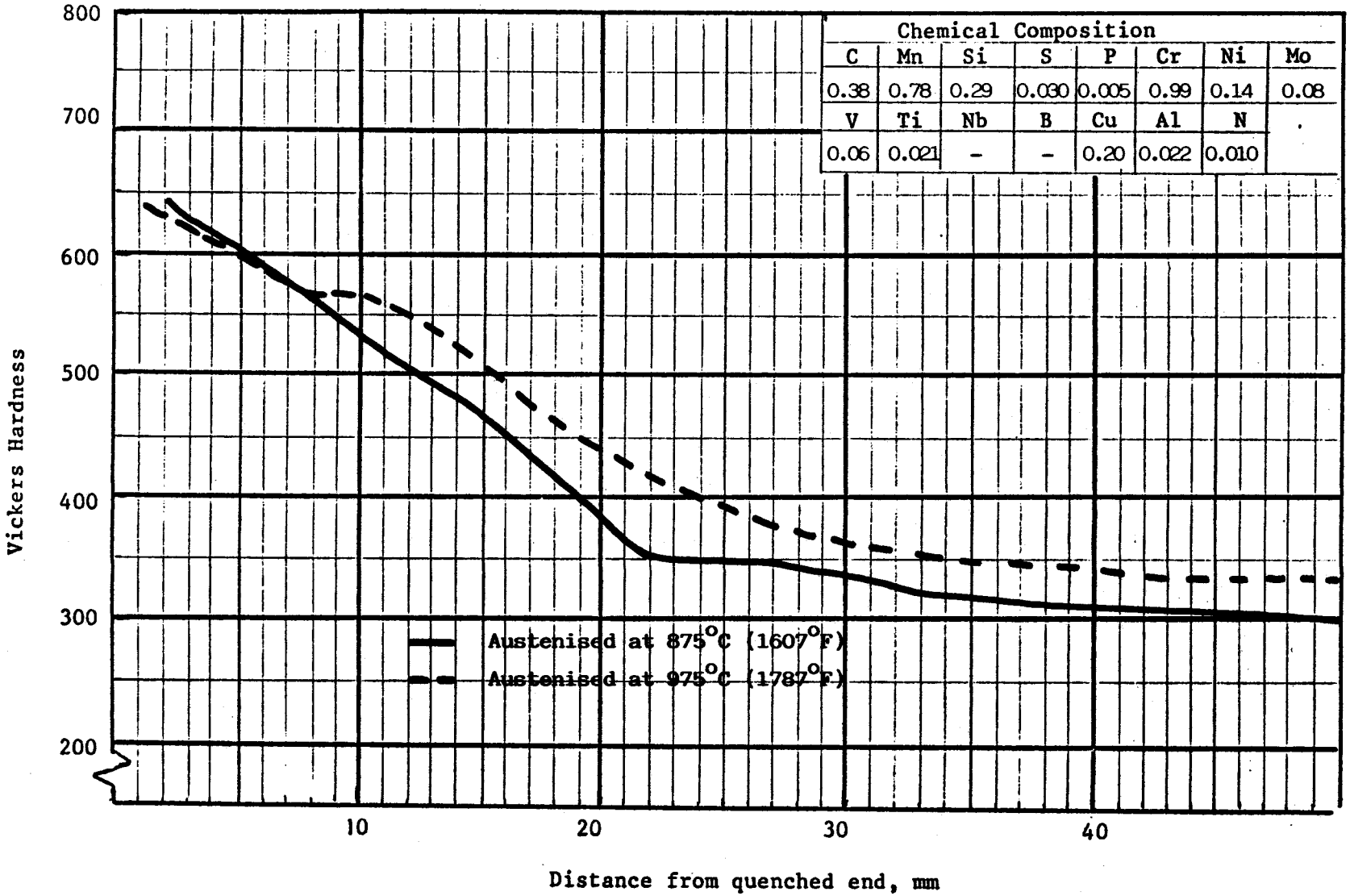
Steel 50



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.38	0.76	0.19	0.050	0.035	0.89	0.02	0.02
V	Ti	Nb	B	Cu	Al	N	
0.02	0.02	-	-	-	0.030	0.010	

Source: Diagram determined by Sheffield University, England
Van ref: 9

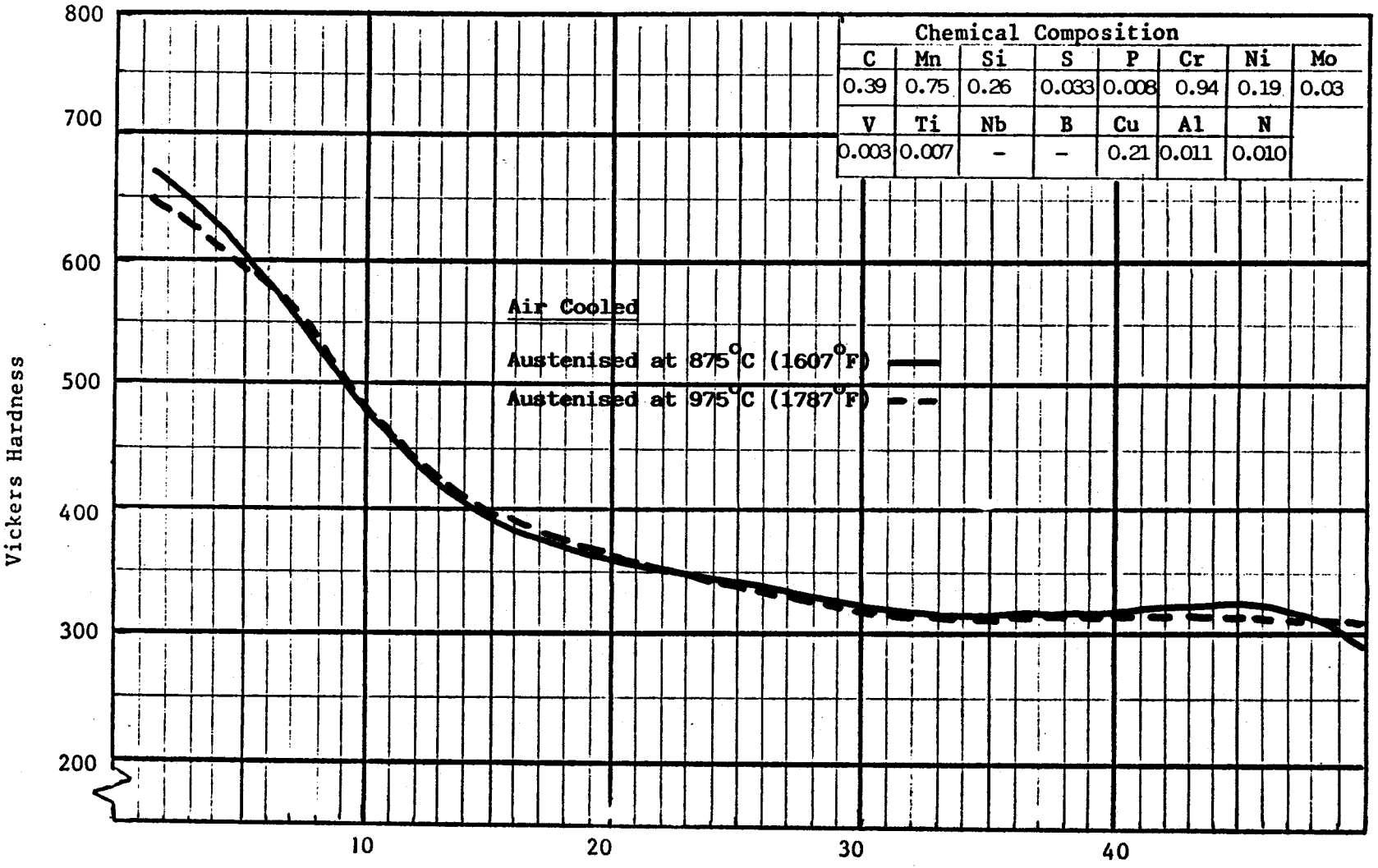
Steel 51



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.38	0.78	0.29	0.030	0.005	0.99	0.14	0.08
V	Ti	Nb	B	Cu	Al	N	
0.06	0.021	-	-	0.20	0.022	0.010	

Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 48

Steel 52a

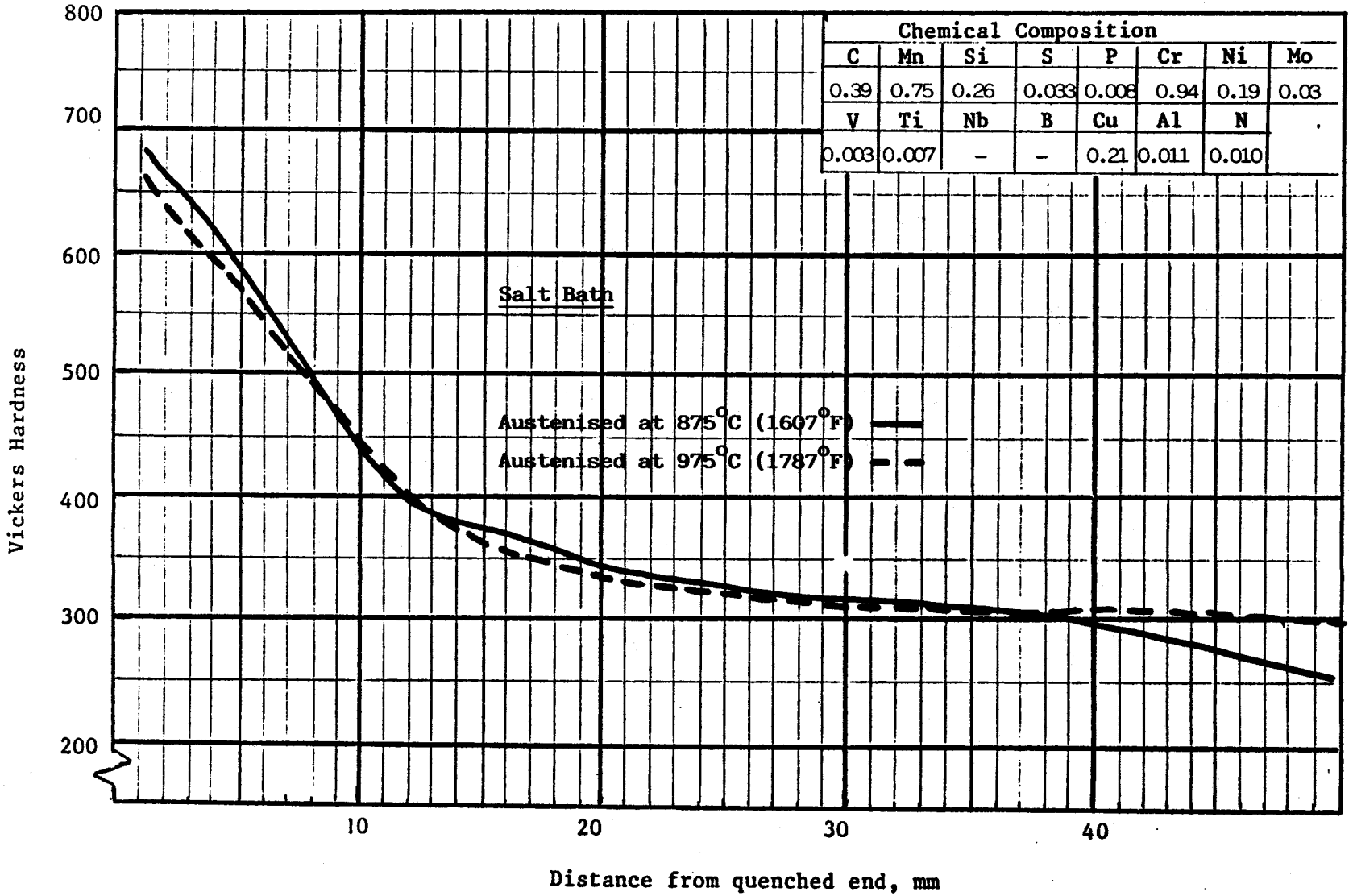


Chemical Composition

C	Mn	Si	S	P	Cr	Ni	Mo
0.39	0.75	0.26	0.033	0.008	0.94	0.19	0.03
V	**Ti**	**Nb**	**B**	**Cu**	**Al**	**N**	
0.003	0.007	-	-	0.21	0.011	0.010	

Source: Diagram determined by Institutet for Metallforskning, Sweden.
Van ref: 35

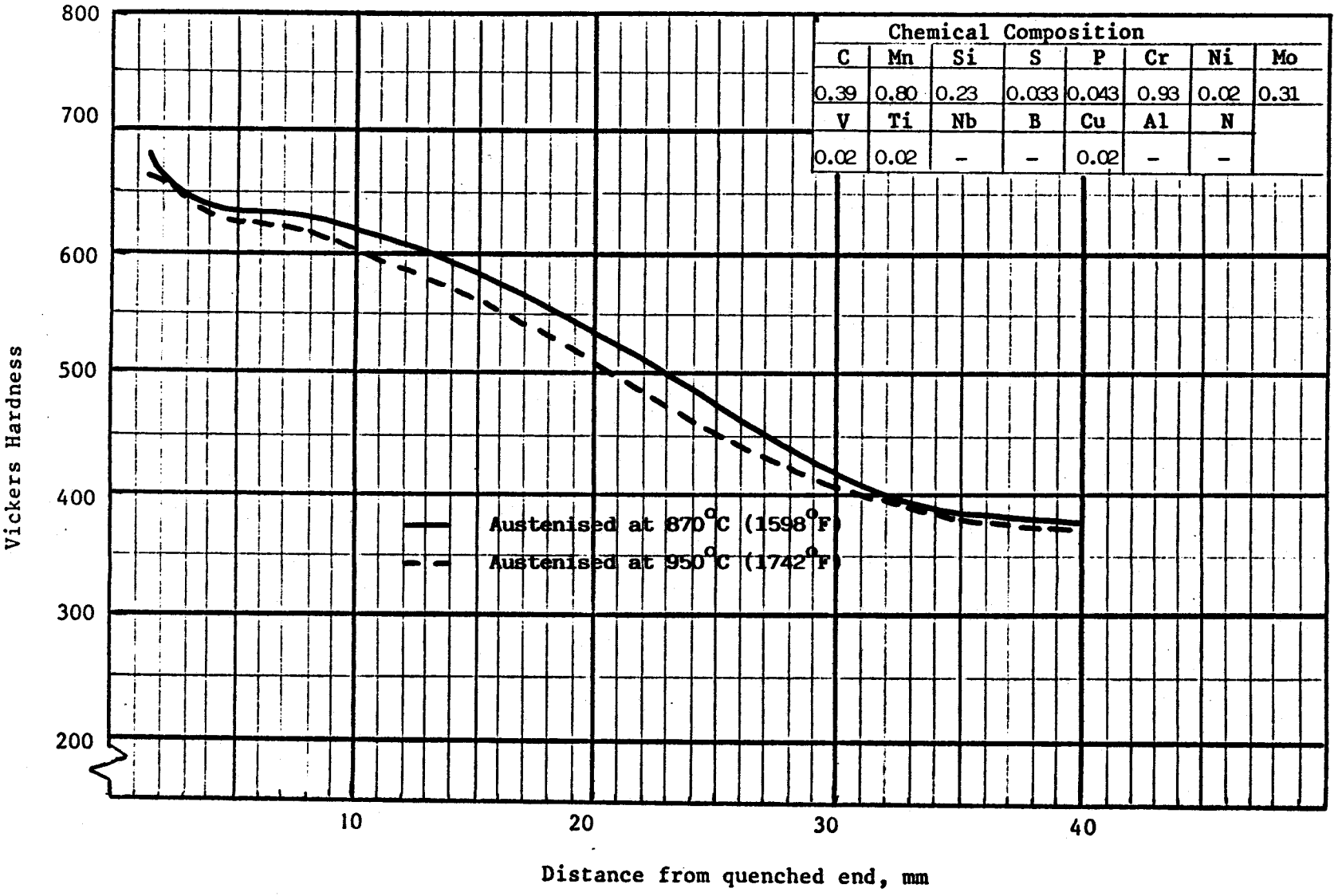
Steel 52b



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.39	0.75	0.26	0.033	0.008	0.94	0.19	0.03
V	Ti	Nb	B	Cu	Al	N	
0.003	0.007	-	-	0.21	0.011	0.010	

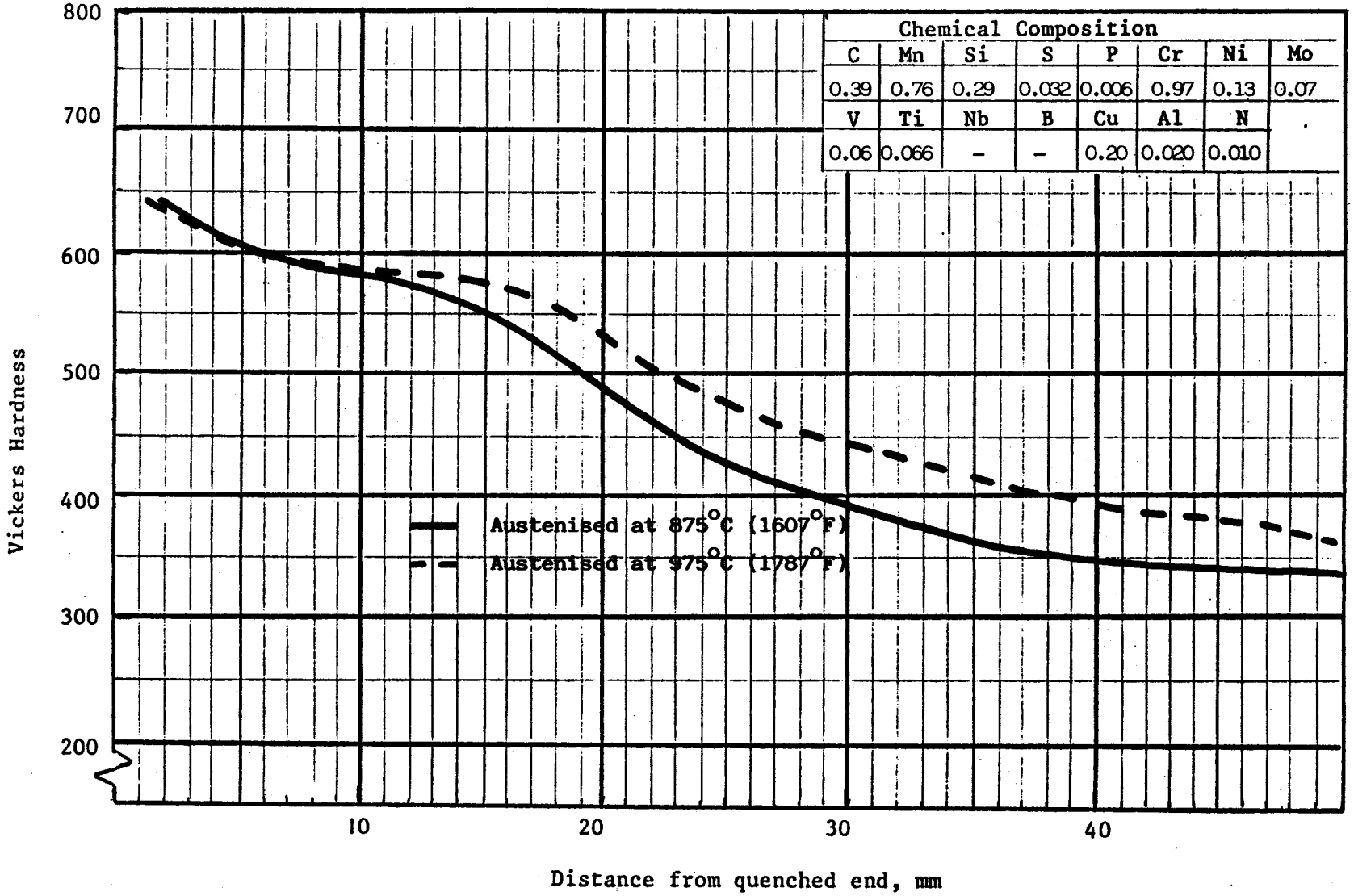
Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 35

Steel 53



Source: Diagram determined by Sheffield University, England.
Van ref: 24

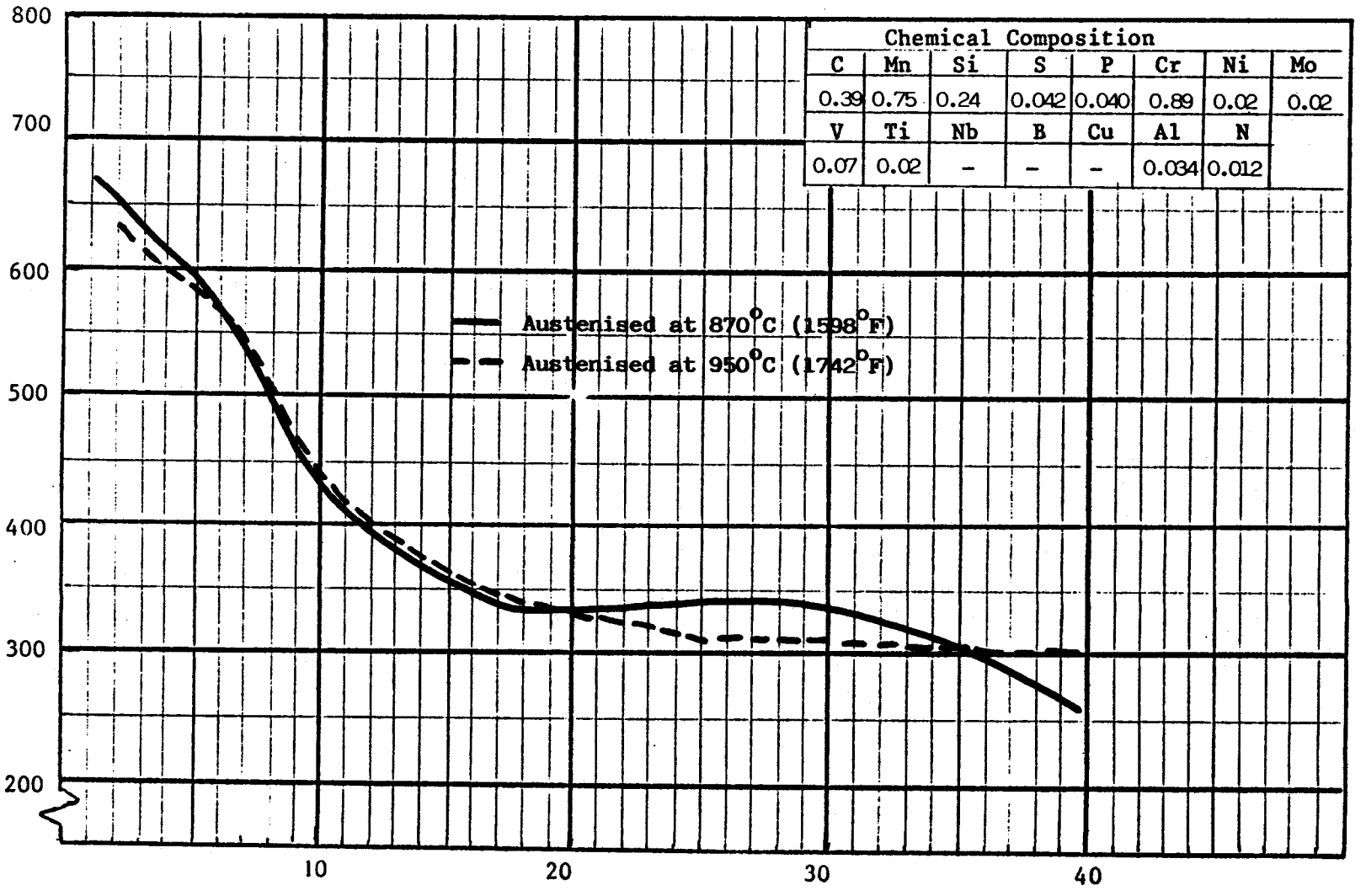
Steel 54



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.39	0.76	0.29	0.032	0.006	0.97	0.13	0.07
V	Ti	Nb	B	Cu	Al	N	
0.06	0.066	-	-	0.20	0.020	0.010	

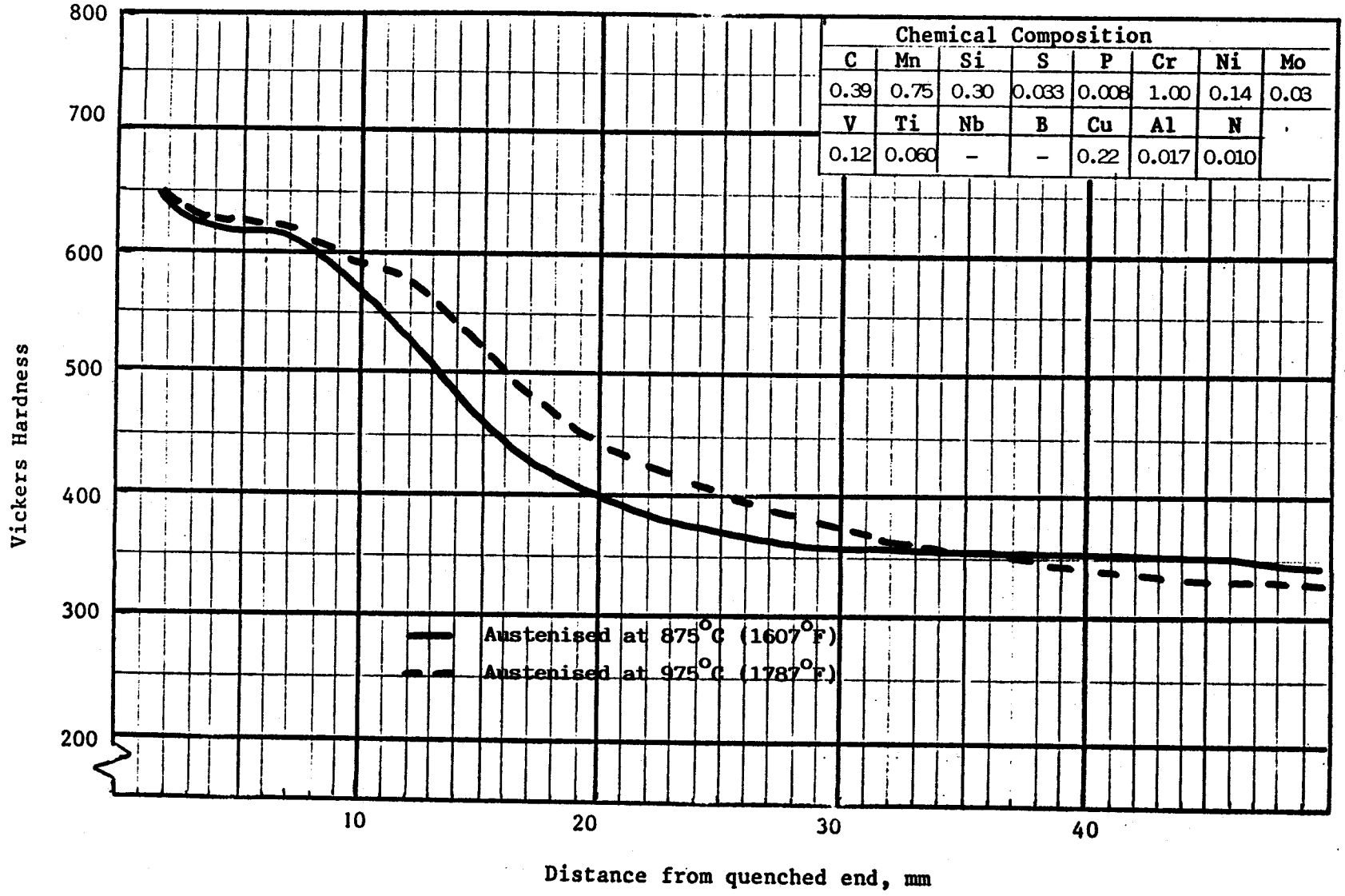
Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 47

Steel 55



Source: Diagram determined by Sheffield University, England
Van ref: 10

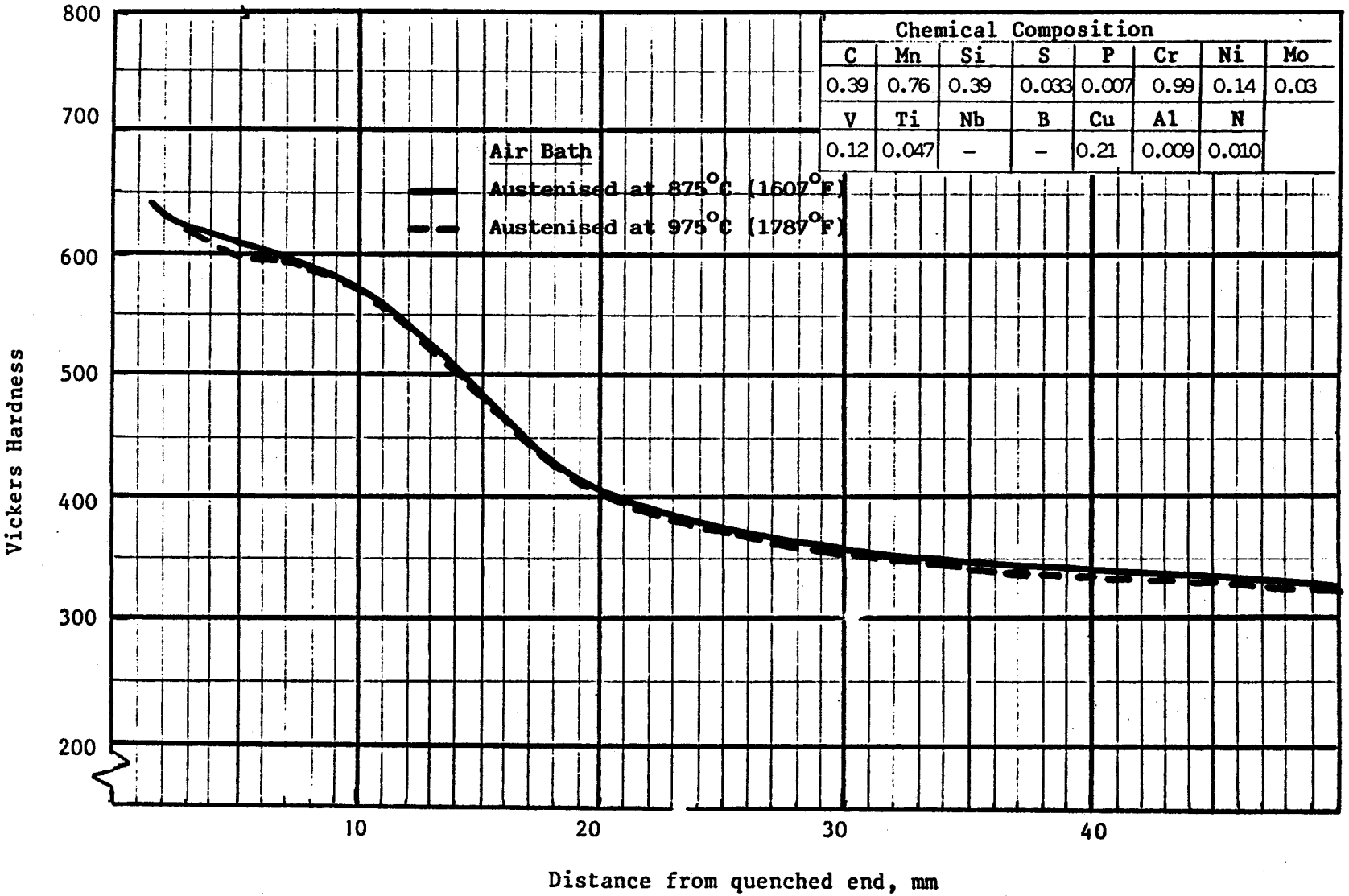
Steel 56



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.39	0.75	0.30	0.033	0.008	1.00	0.14	0.03
V	Ti	Nb	B	Cu	Al	N	
0.12	0.060	–	–	0.22	0.017	0.010	

Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 43

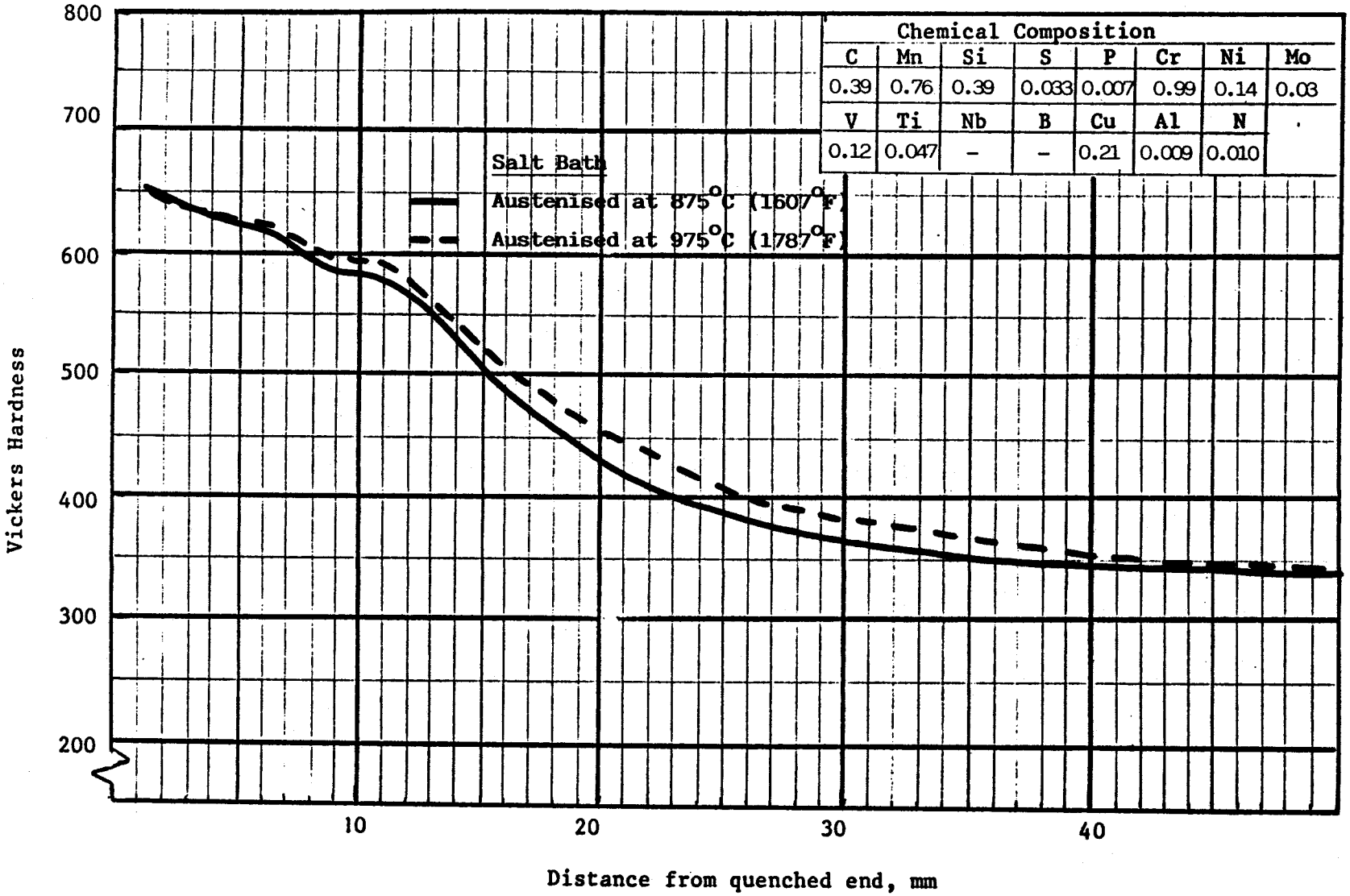
Steel 57a



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.39	0.76	0.39	0.033	0.007	0.99	0.14	0.03
V	Ti	Nb	B	Cu	Al	N	
0.12	0.047	-	-	0.21	0.009	0.010	

Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 41

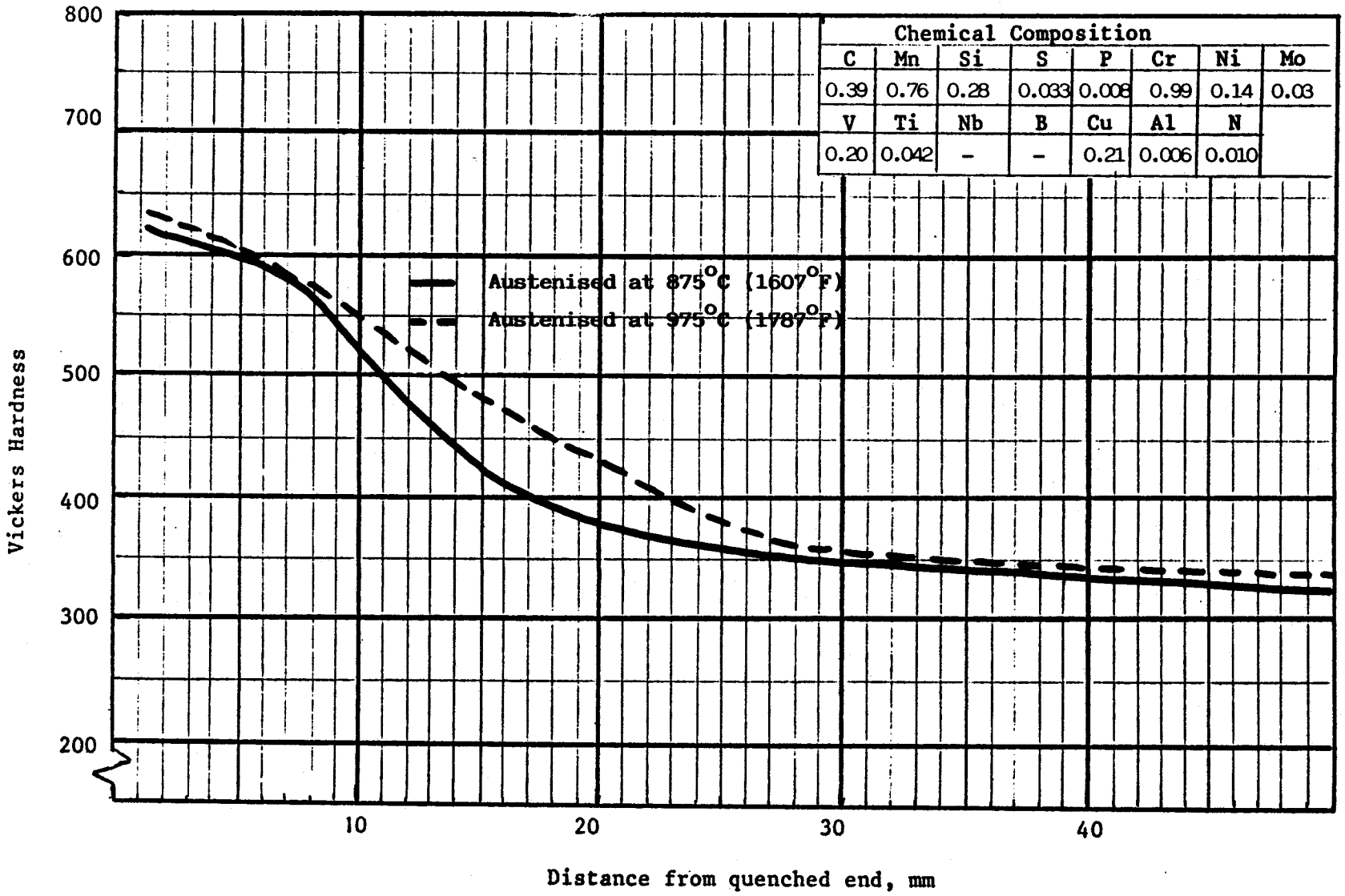
Steel 57b



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.39	0.76	0.39	0.033	0.007	0.99	0.14	0.03
V	Ti	Nb	B	Cu	Al	N	
0.12	0.047	-	-	0.21	0.009	0.010	

Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 41

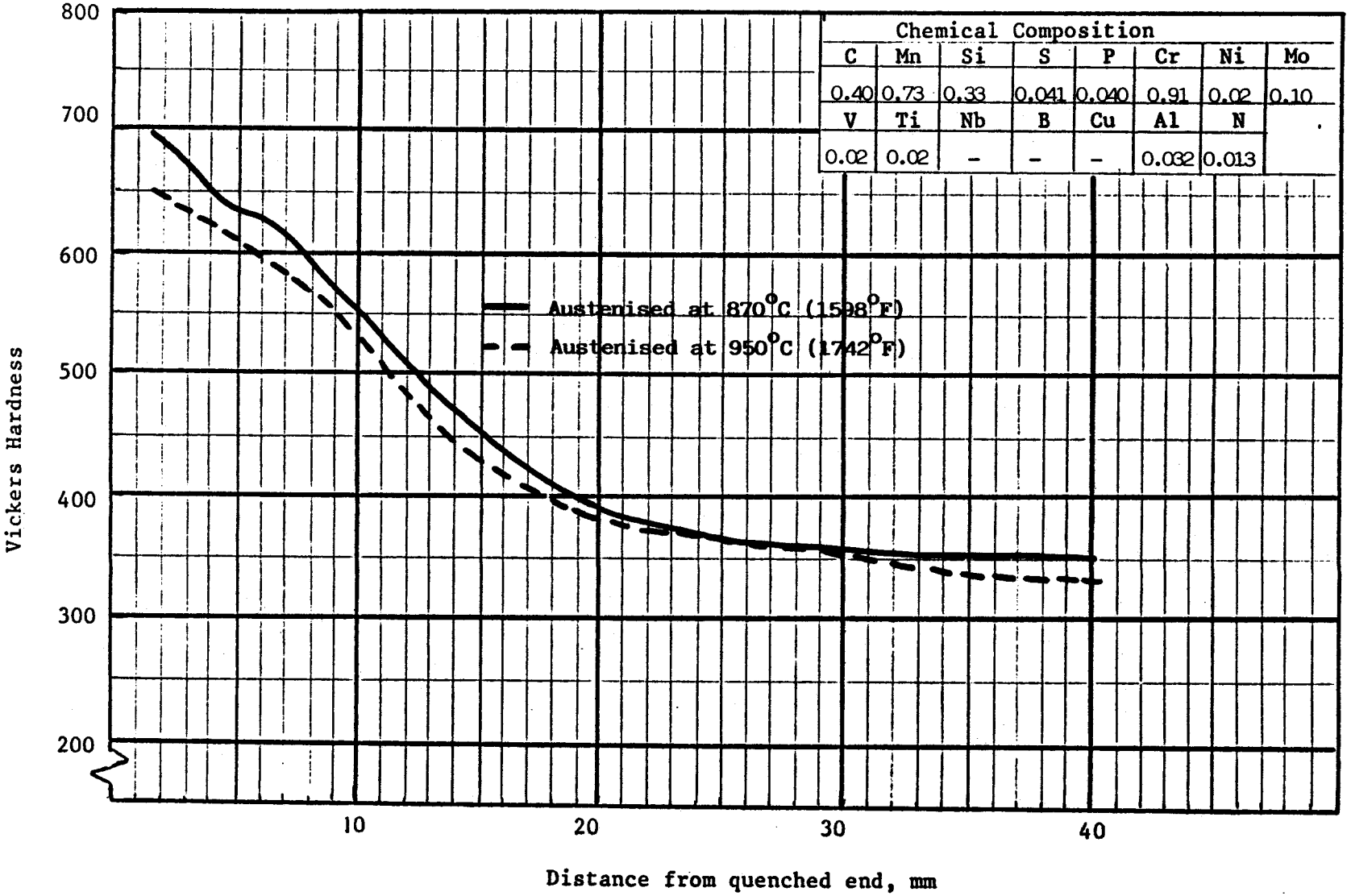
Steel 58



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.39	0.76	0.28	0.033	0.008	0.99	0.14	0.03
V	Ti	Nb	B	Cu	Al	N	
0.20	0.042	-	-	0.21	0.006	0.010	

Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 42

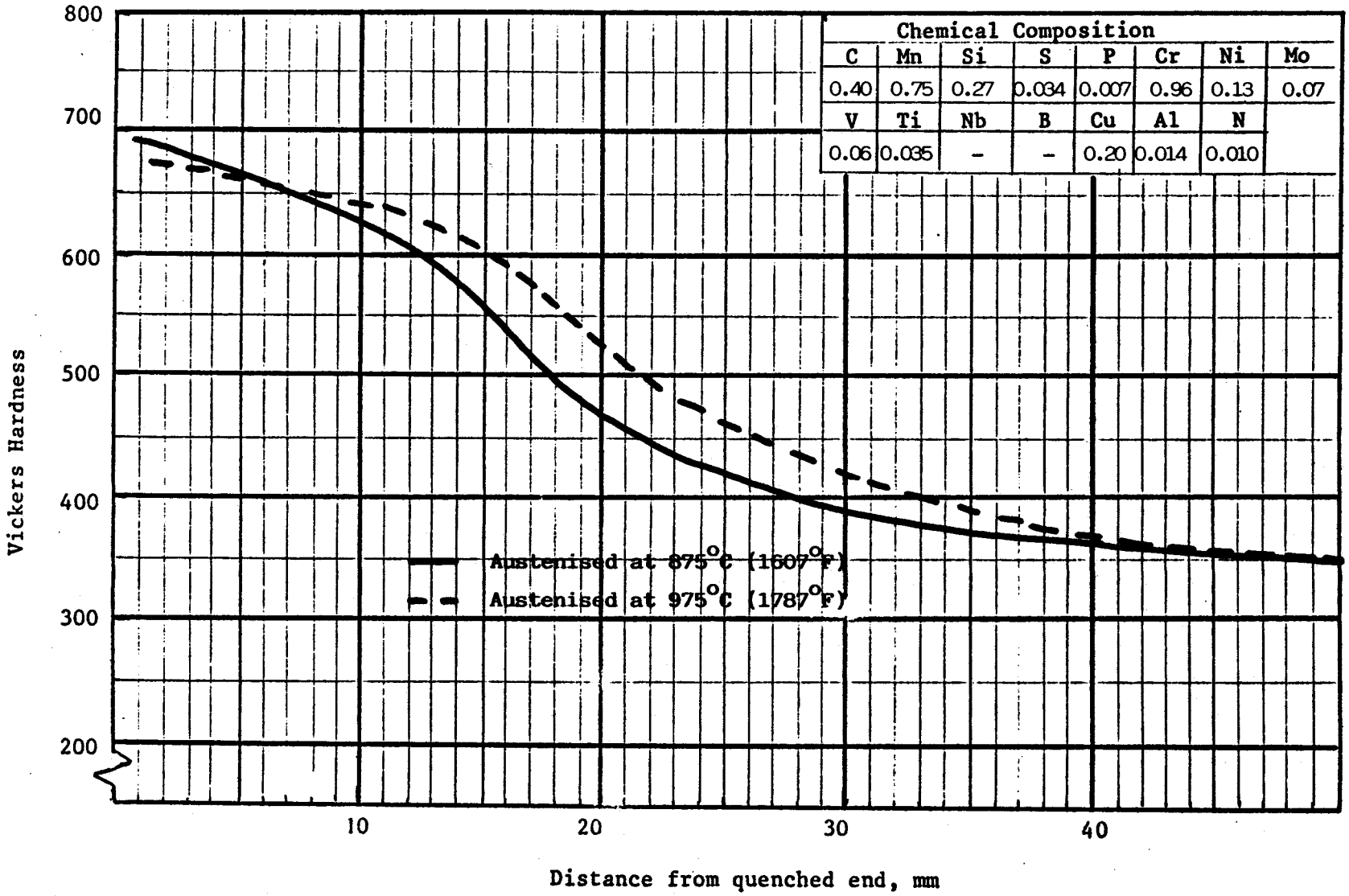
Steel 59



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.40	0.73	0.33	0.041	0.040	0.91	0.02	0.10
V	Ti	Nb	B	Cu	Al	N	
0.02	0.02	-	-	-	0.032	0.013	

Source: Diagram determined by Sheffield University, England
Van ref: 11

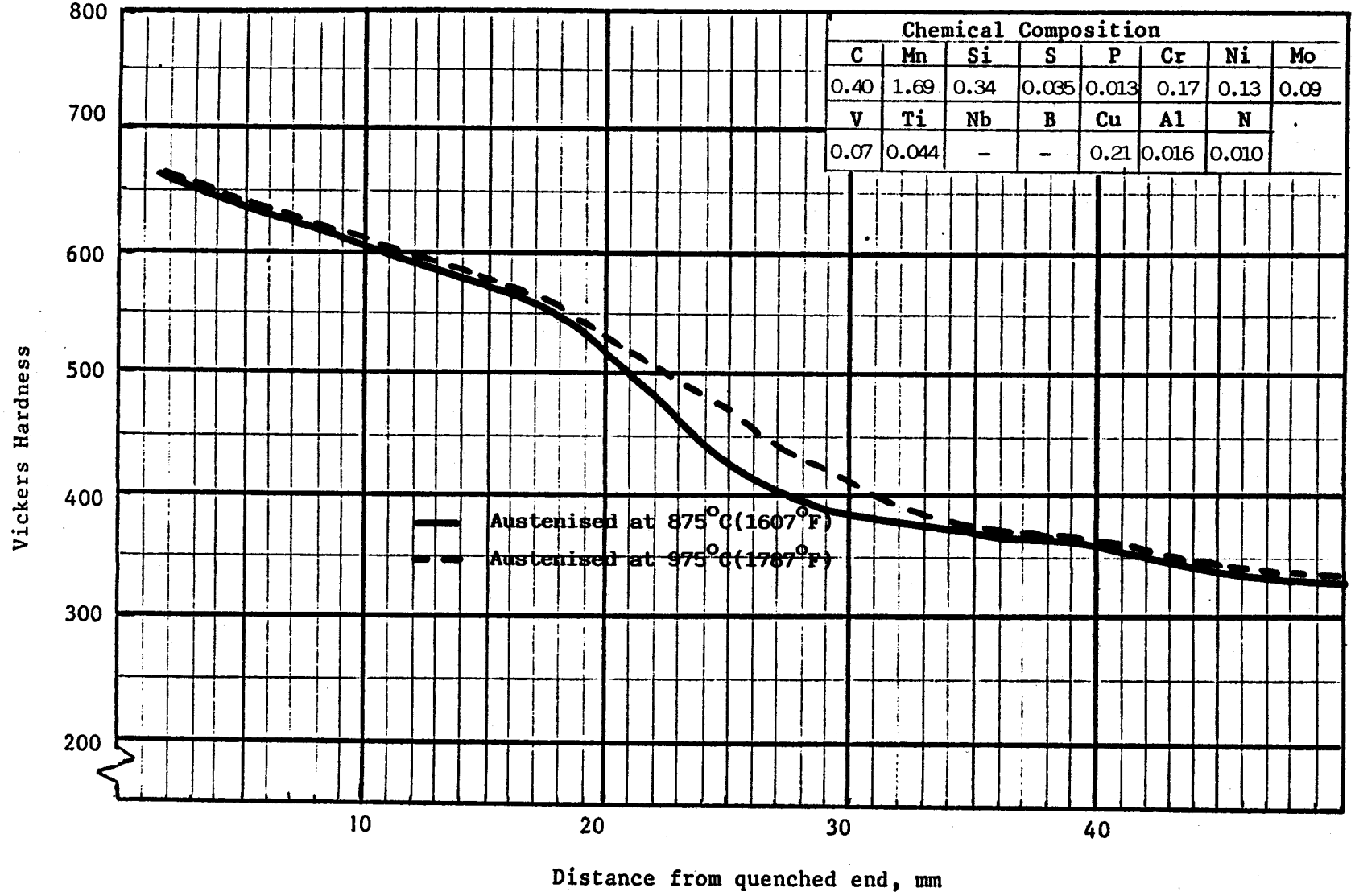
Steel 60



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.40	0.75	0.27	0.034	0.007	0.96	0.13	0.07
V	Ti	Nb	B	Cu	Al	N	
0.06	0.035	-	-	0.20	0.014	0.010	

Source: Diagram determined by Institutet for Metallfoskning, Sweden
Van ref: 37

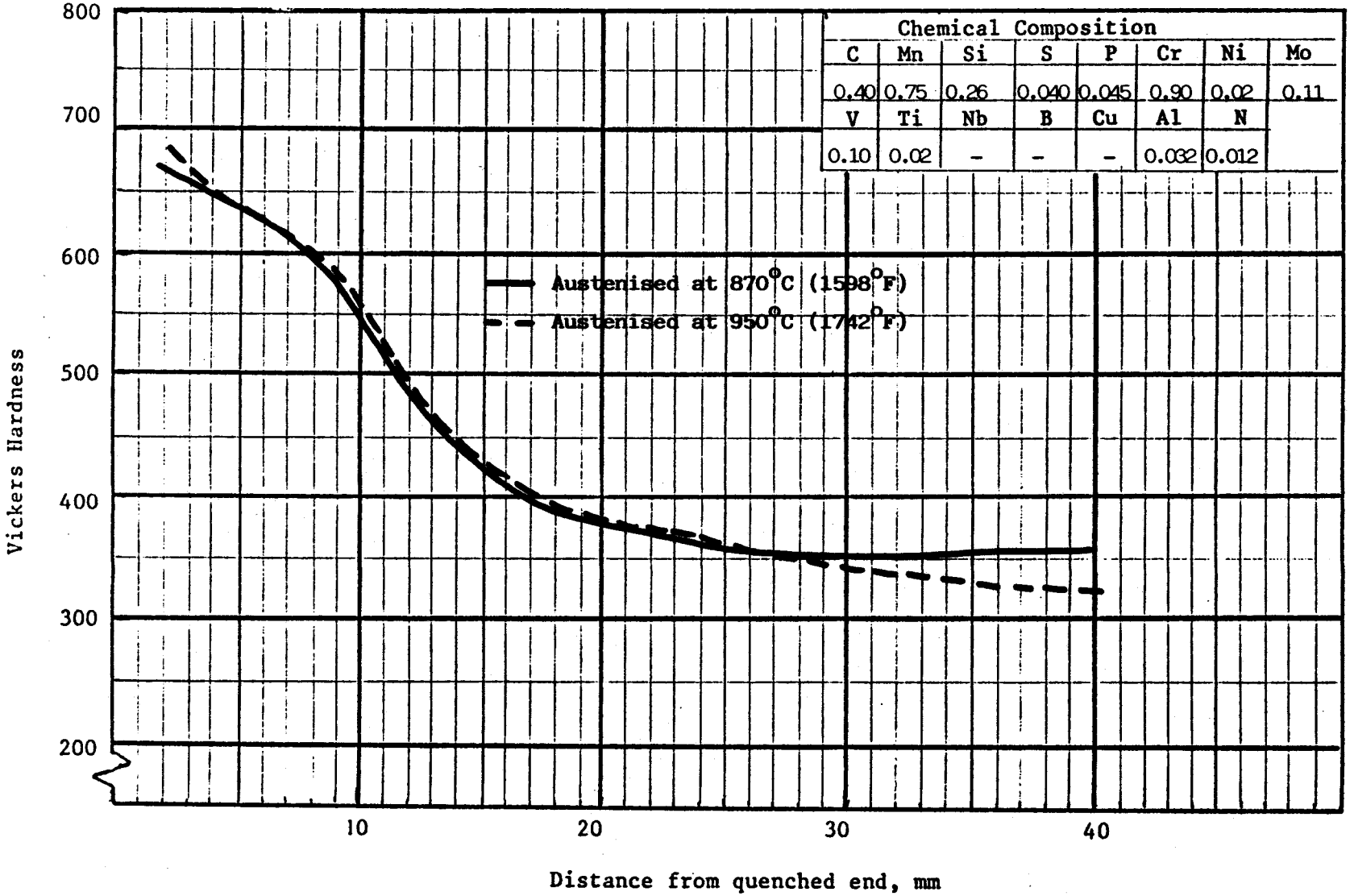
Steel 61



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.40	1.69	0.34	0.035	0.013	0.17	0.13	0.09
V	Ti	Nb	B	Cu	Al	N	
0.07	0.044	-	-	0.21	0.016	0.010	

Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 44

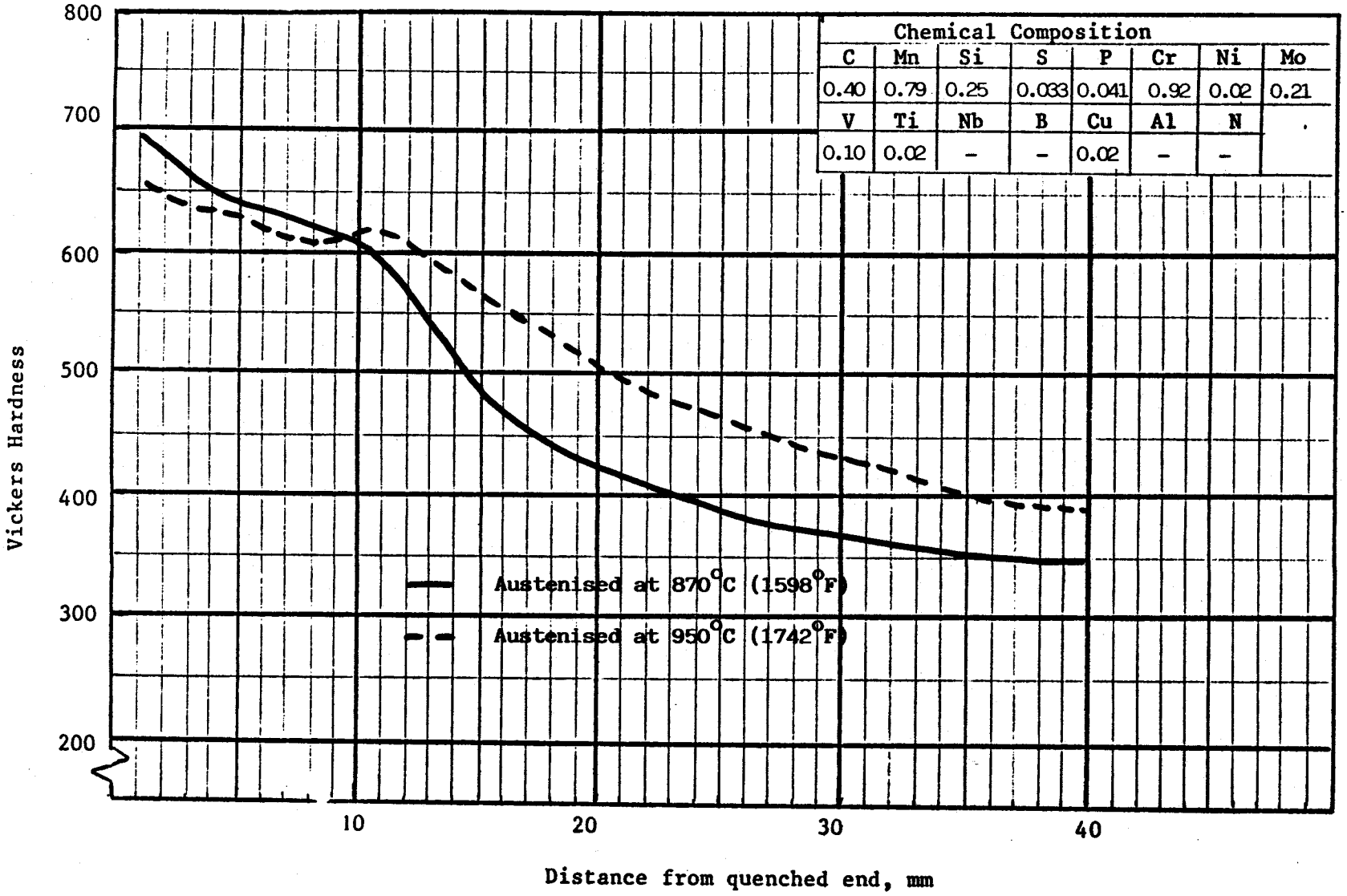
Steel 62



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.40	0.75	0.26	0.040	0.045	0.90	0.02	0.11
V	Ti	Nb	B	Cu	Al	N	
0.10	0.02	-	-	-	0.032	0.012	

Source: Diagram determined by Sheffield University, England
Van ref: 12

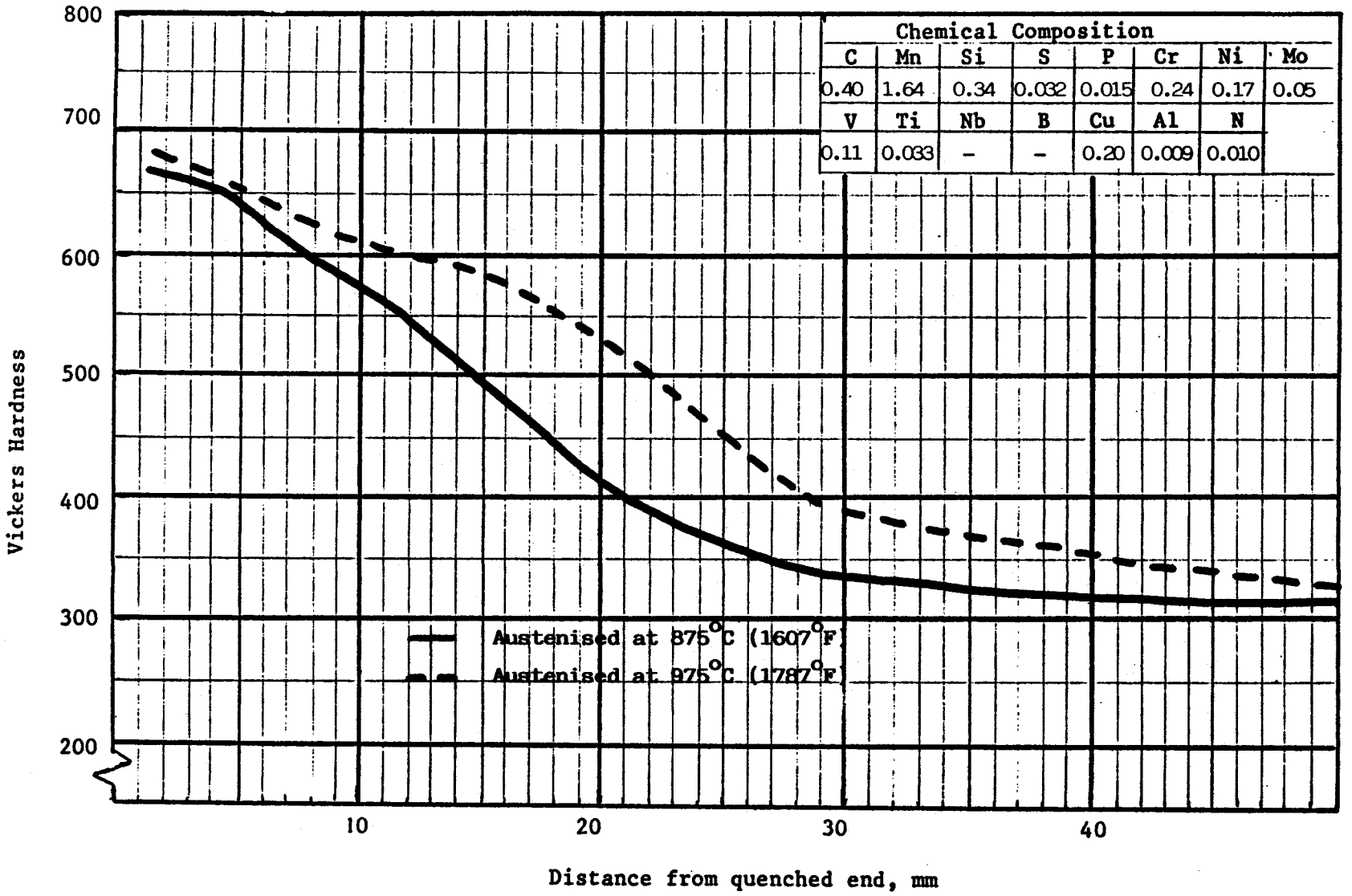
Steel 63



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.40	0.79	0.25	0.033	0.041	0.92	0.02	0.21
V	Ti	Nb	B	Cu	Al	N	
0.10	0.02	-	-	0.02	-	-	

Source: Diagram determined by Sheffield University, England.
Van ref: 26

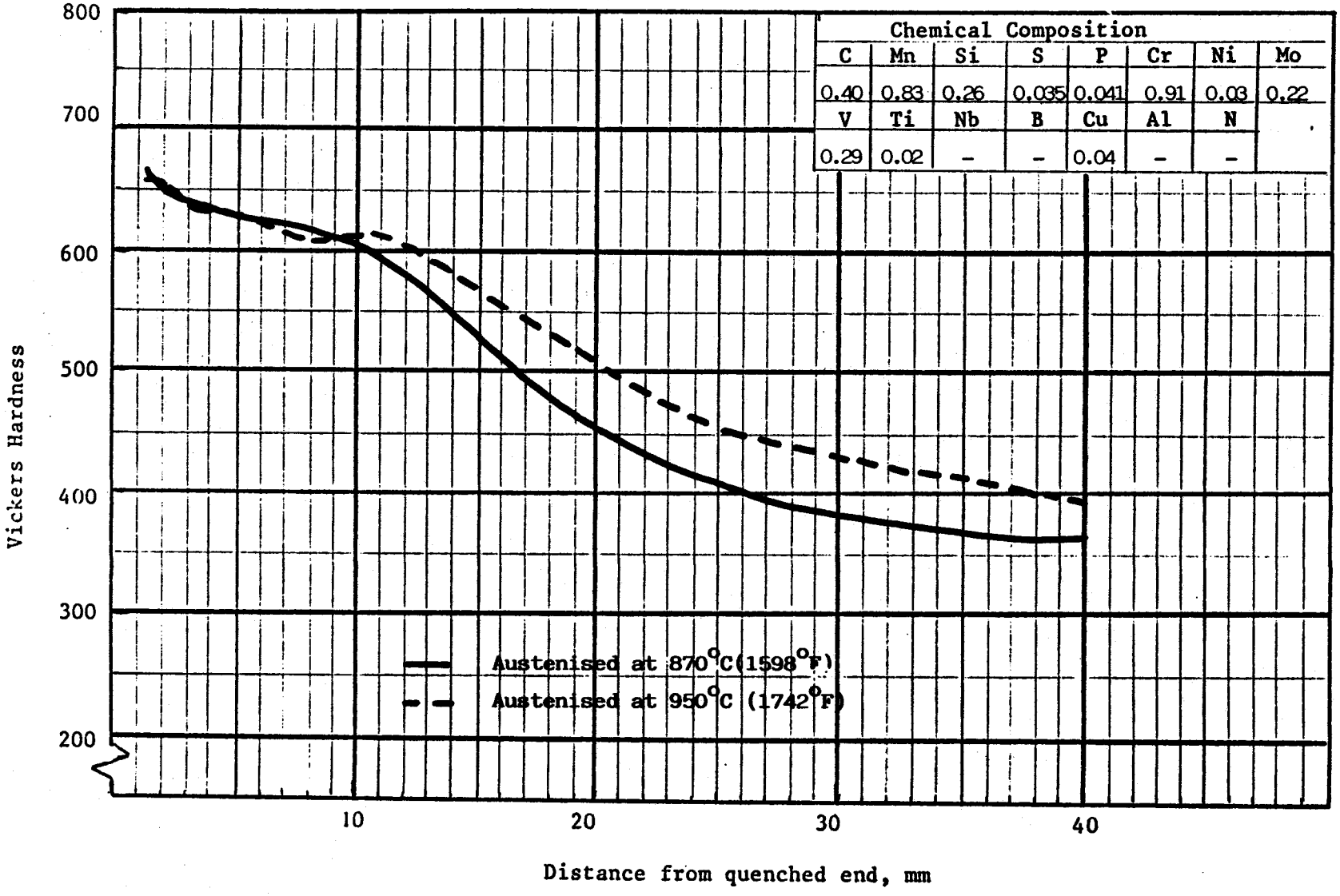
Steel 64



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.40	1.64	0.34	0.032	0.015	0.24	0.17	0.05
V	Ti	Nb	B	Cu	Al	N	
0.11	0.033	-	-	0.20	0.009	0.010	

Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 45

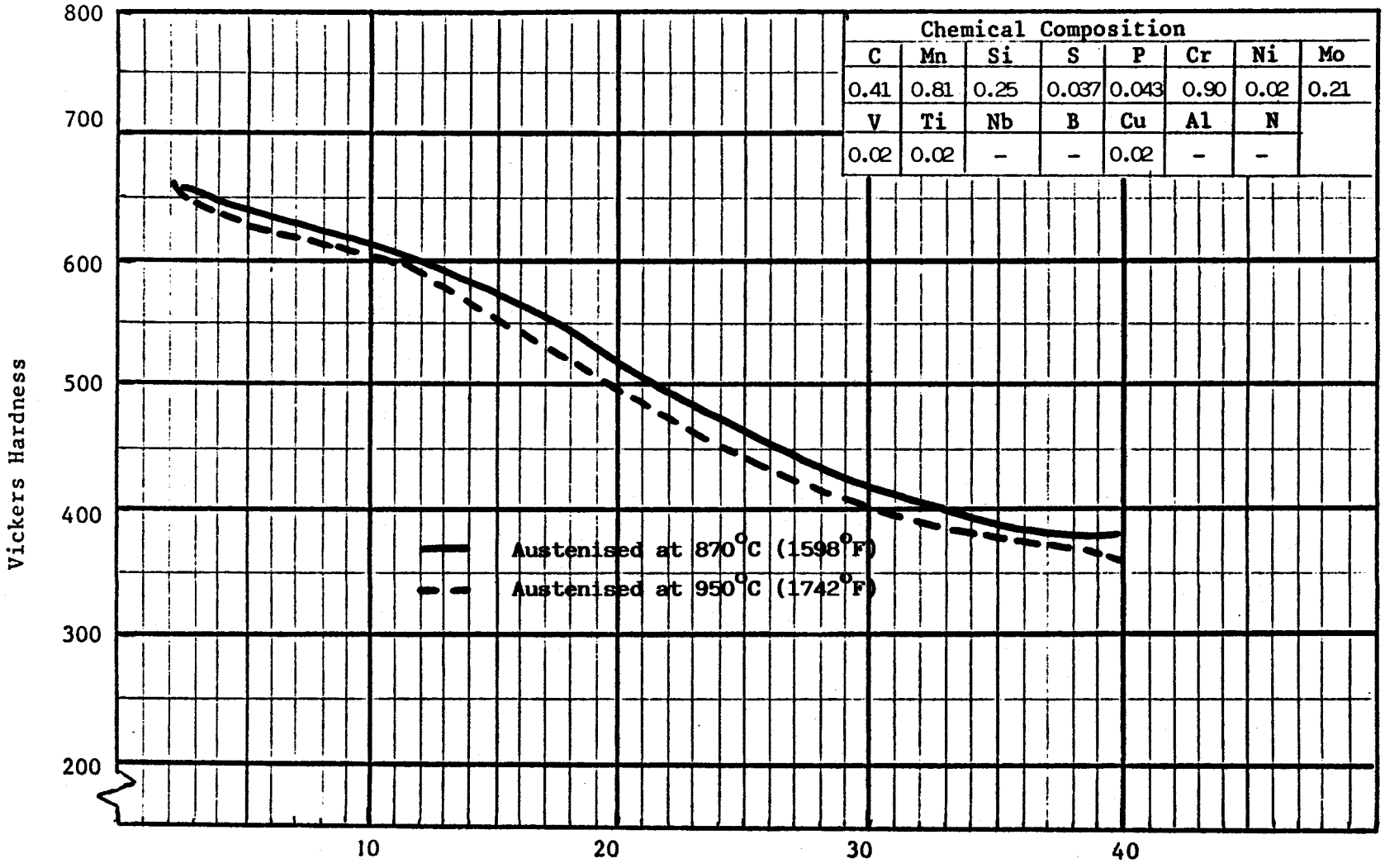
Steel 65



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.40	0.83	0.26	0.035	0.041	0.91	0.03	0.22
V	Ti	Nb	B	Cu	Al	N	
0.29	0.02	–	–	0.04	–	–	

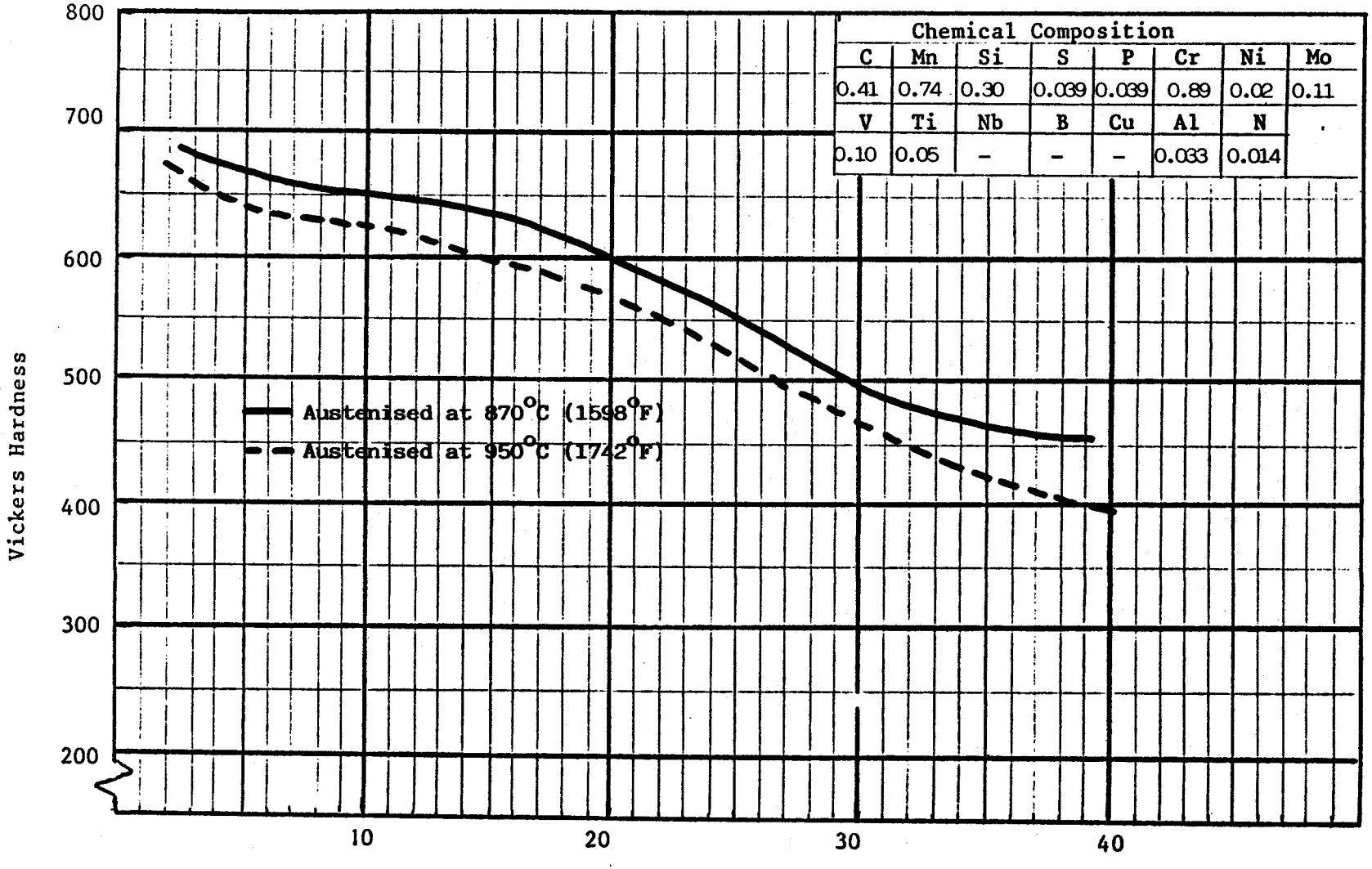
Source: Diagram determined by Sheffield University, England.
Van ref: 27

Steel 66



Source: Diagram determined by Sheffield University, England.
Van ref: 23

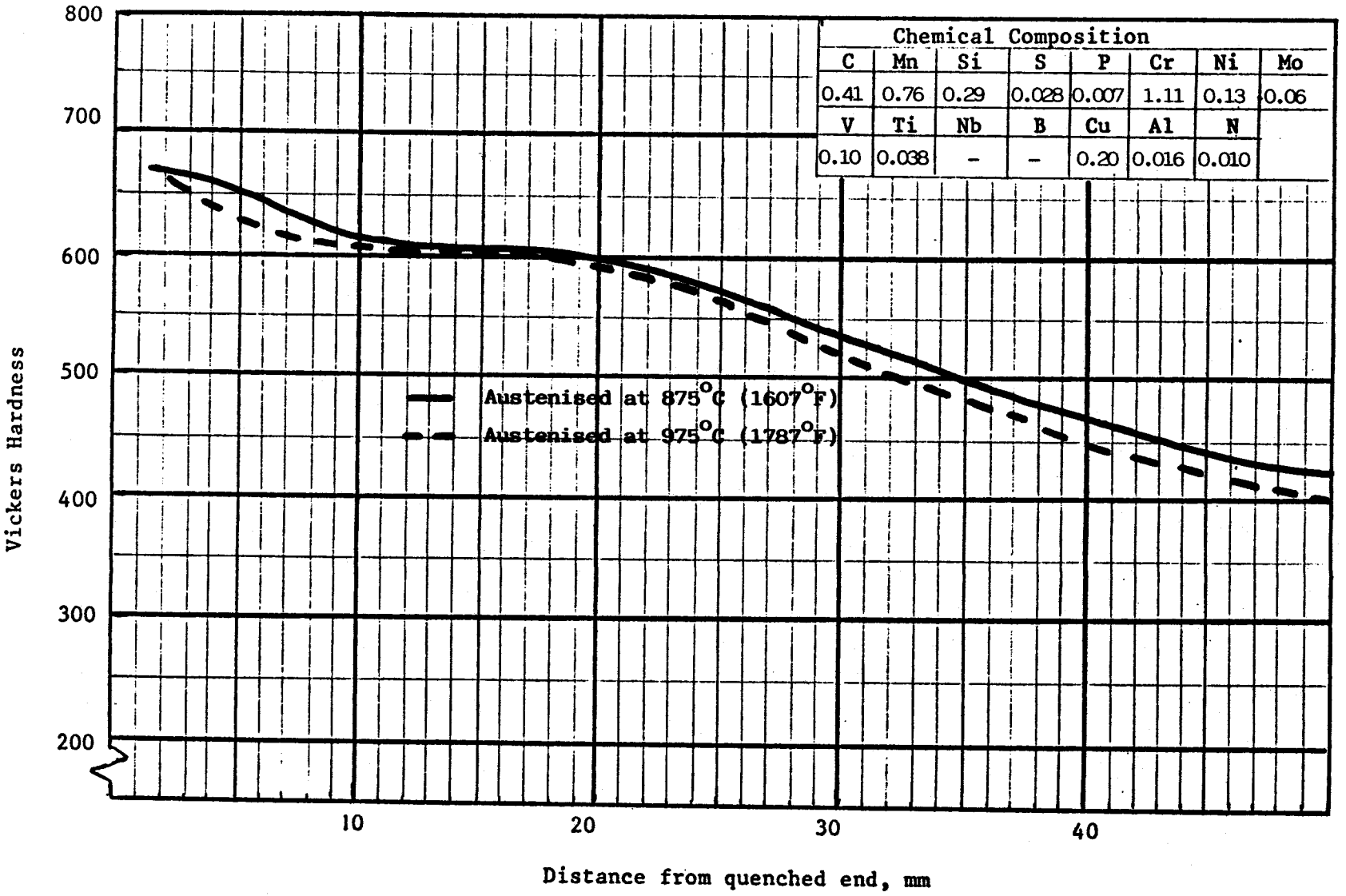
Steel 67



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.41	0.74	0.30	0.039	0.039	0.89	0.02	0.11
V	Ti	Nb	B	Cu	Al	N	
0.10	0.05	–	–	–	0.033	0.014	

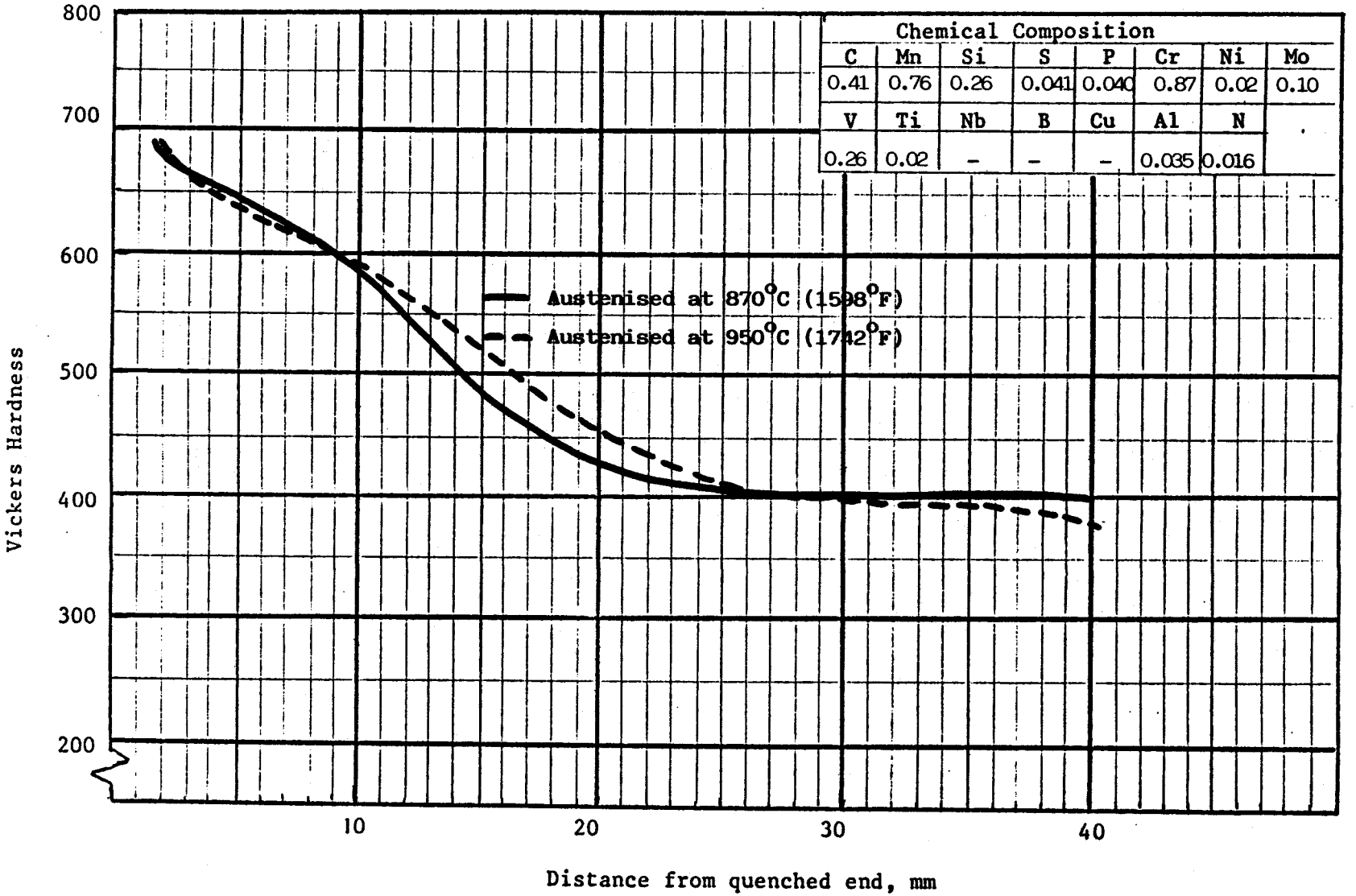
Source: Diagram determined by Sheffield University, England.
Van ref: 15

Steel 68



Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 52

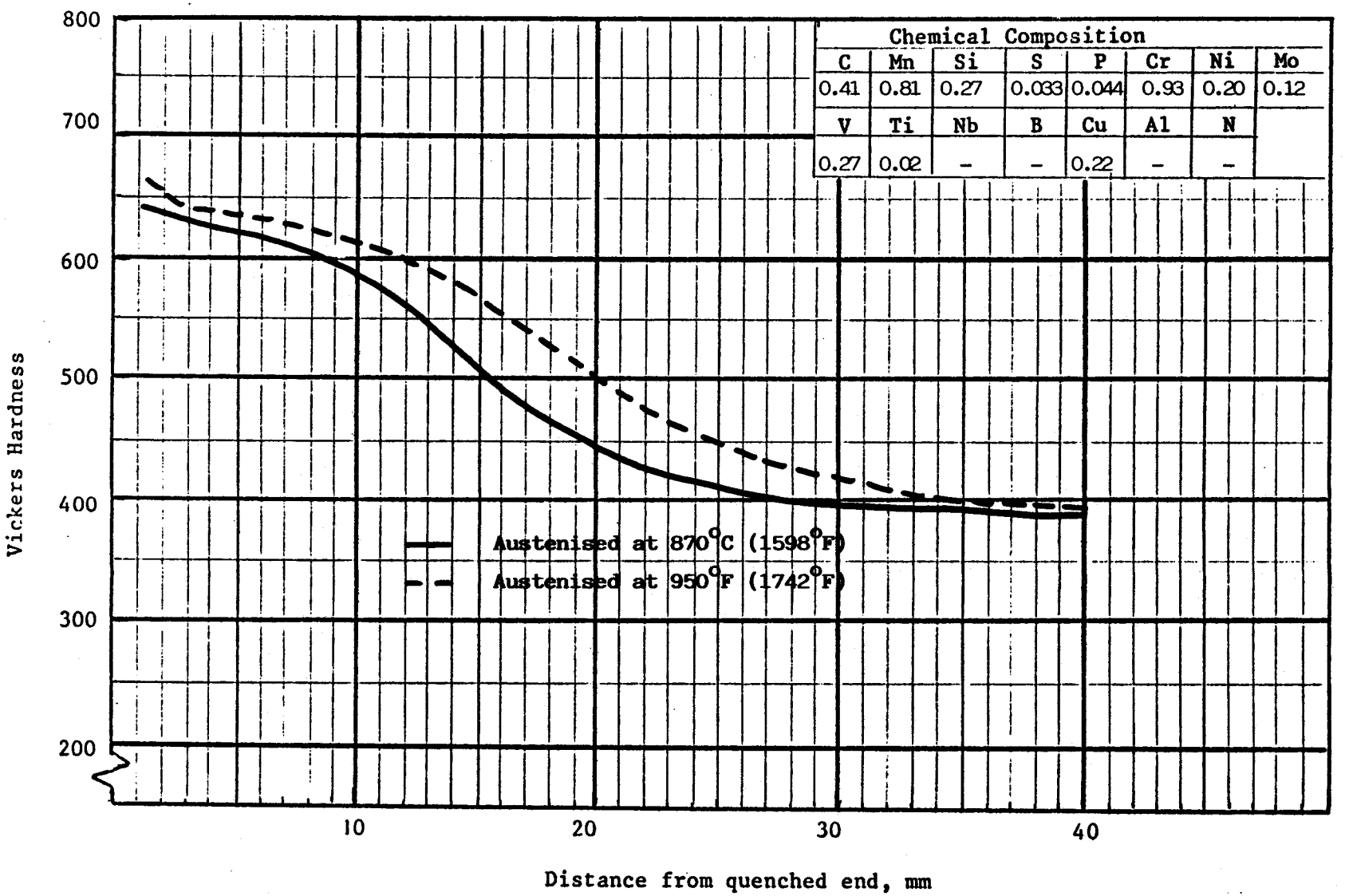
Steel 69



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.41	0.76	0.26	0.041	0.040	0.87	0.02	0.10
V	Ti	Nb	B	Cu	Al	N	
0.26	0.02	–	–	–	0.035	0.016	

Source: Diagram determined by Sheffield University, England.
Van ref: 14

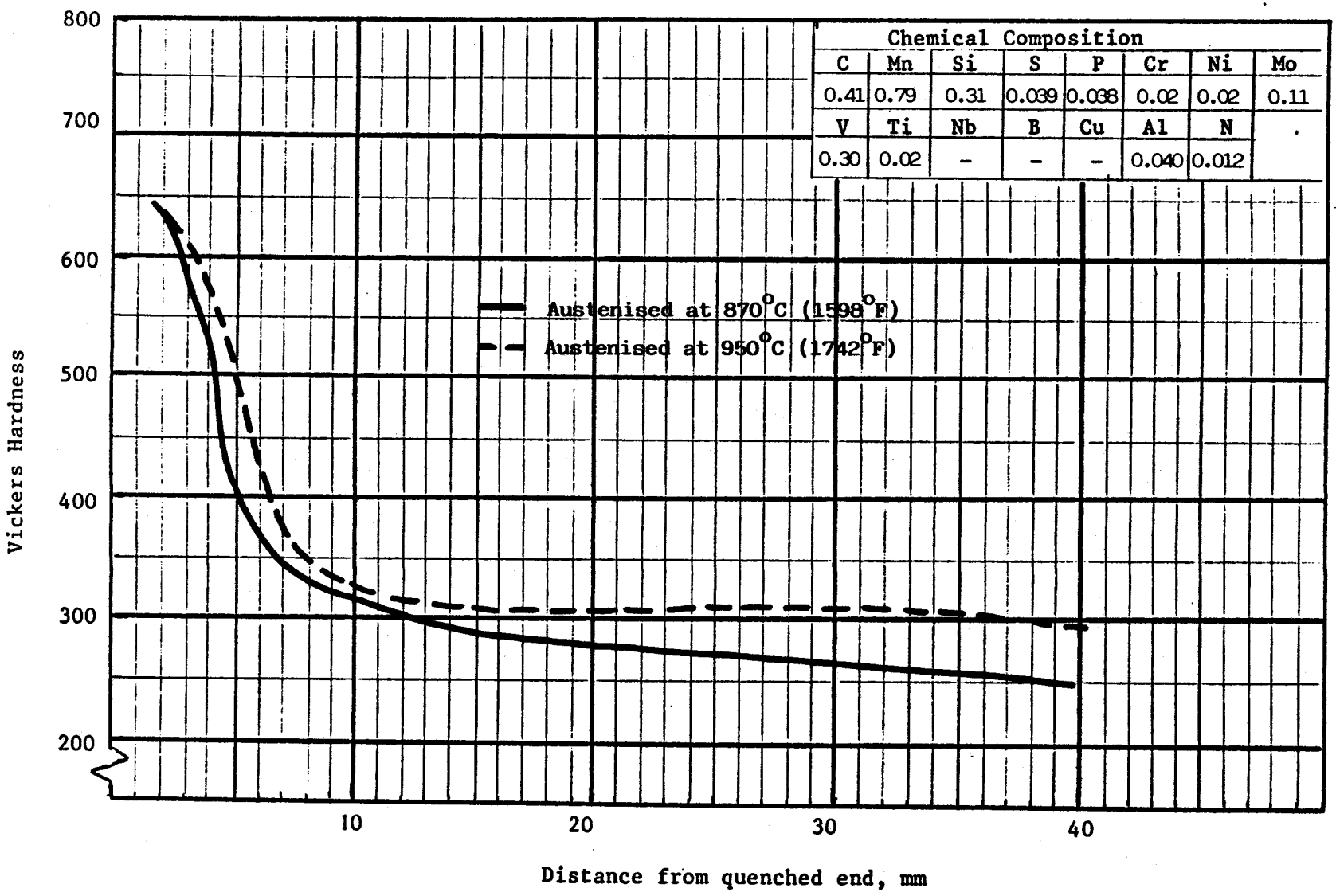
Steel 70



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.41	0.81	0.27	0.033	0.044	0.93	0.20	0.12
V	Ti	Nb	B	Cu	Al	N	
0.27	0.02	–	–	0.22	–	–	

Source: Diagram determined by Sheffield University, England.
Van ref: 25

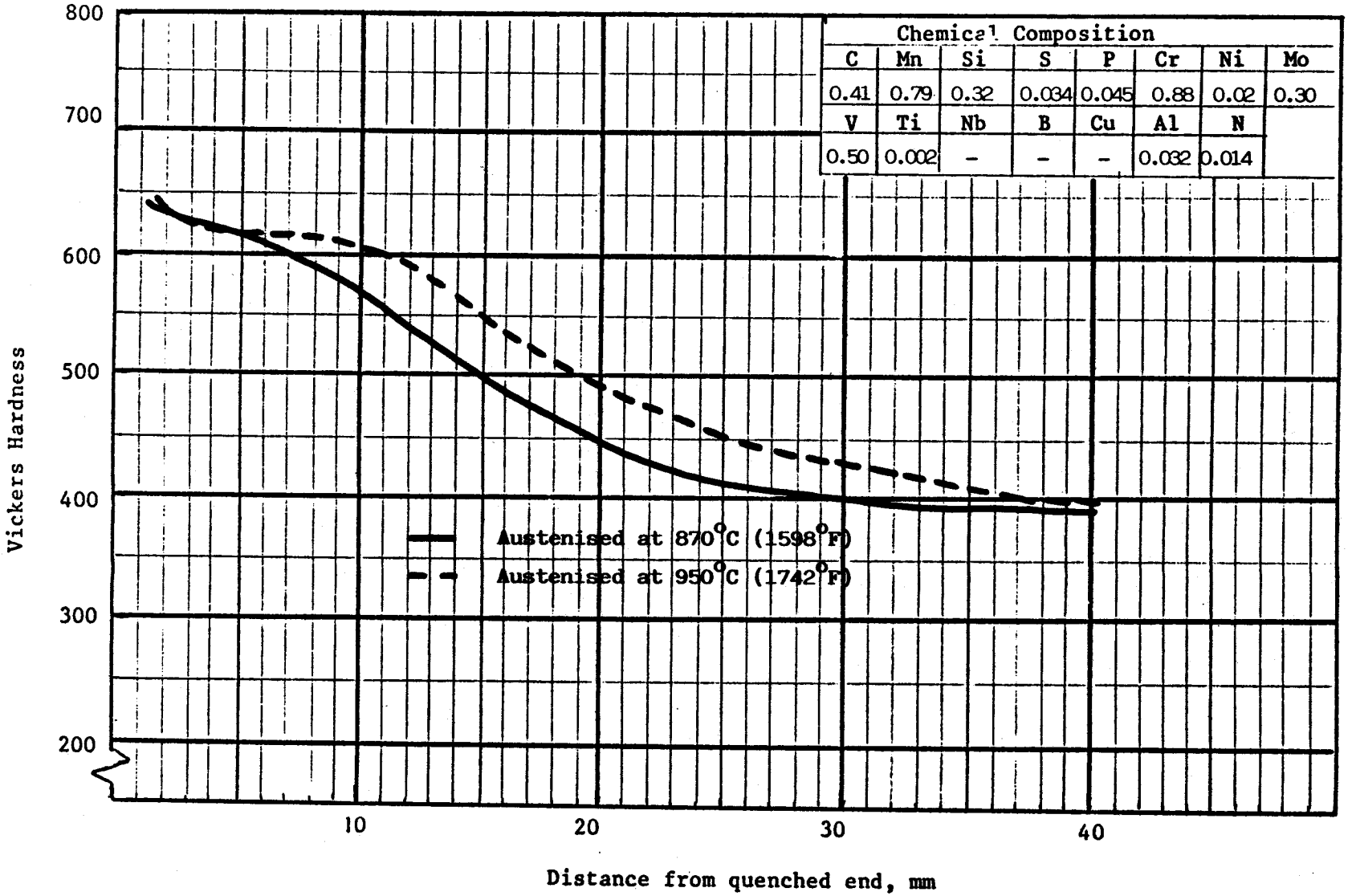
Steel 71



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.41	0.79	0.31	0.039	0.038	0.02	0.02	0.11
V	Ti	Nb	B	Cu	Al	N	
0.30	0.02	-	-	-	0.040	0.012	

Source: Diagram determined by Sheffield University, England.
Van ref: 17

Steel 72

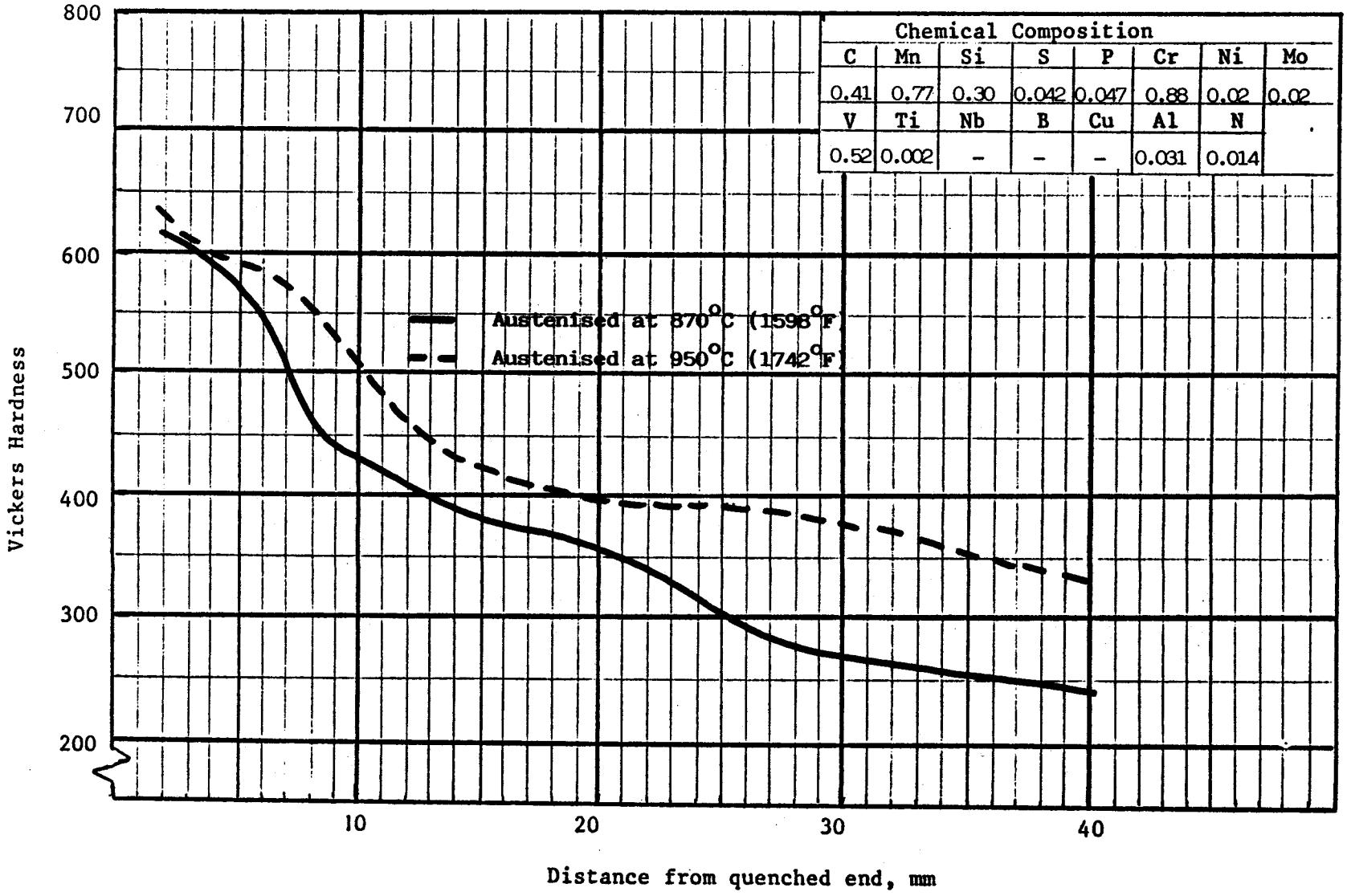


Chemical Composition

C	Mn	Si	S	P	Cr	Ni	Mo
0.41	0.79	0.32	0.034	0.045	0.88	0.02	0.30
V	**Ti**	**Nb**	**B**	**Cu**	**Al**	**N**	
0.50	0.002	-	-	-	0.032	0.014	

Source: Diagram determined by Sheffield University, England
Van ref: 21

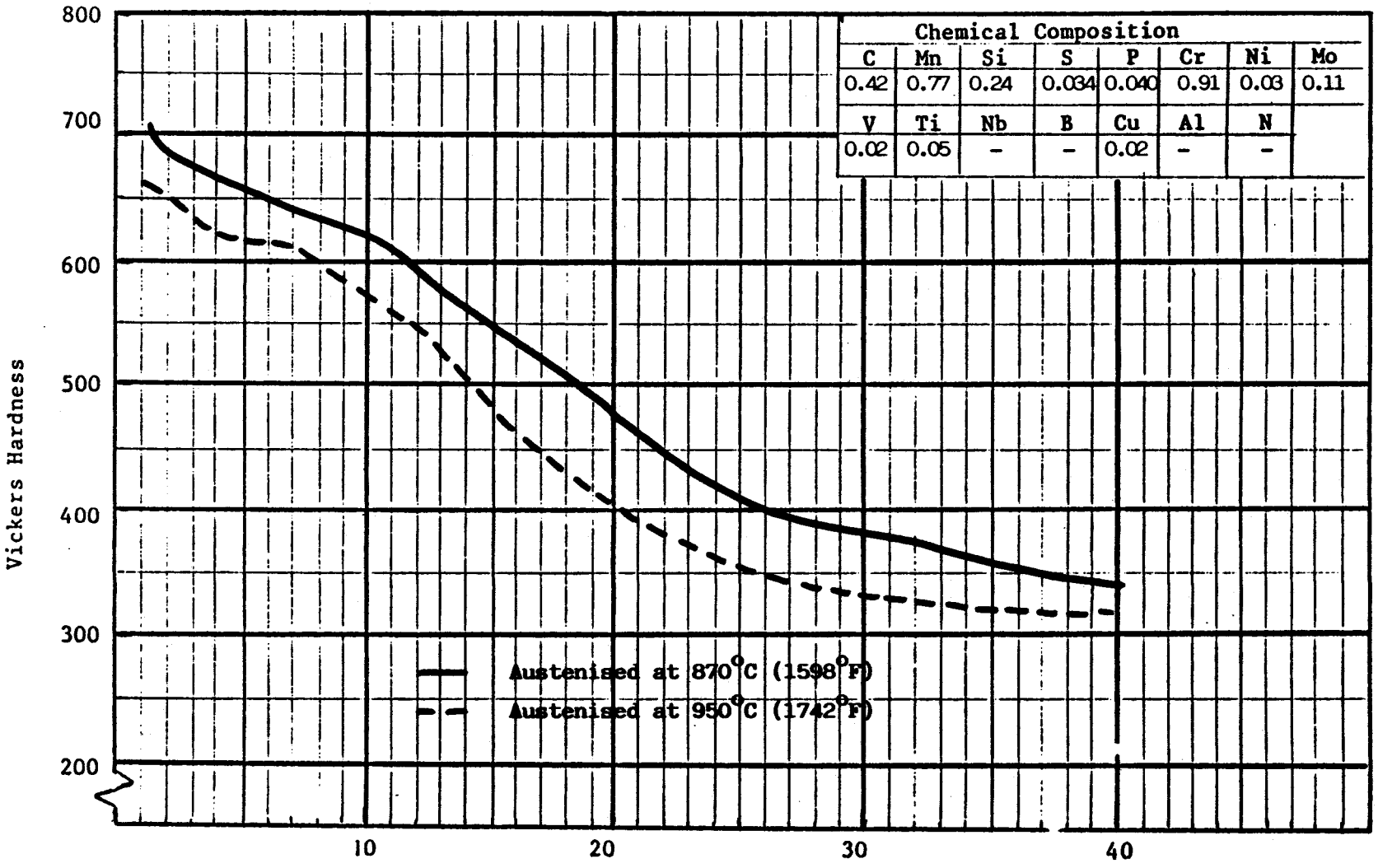
Steel 73



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.41	0.77	0.30	0.042	0.047	0.88	0.02	0.02
V	Ti	Nb	B	Cu	Al	N	
0.52	0.002	-	-	-	0.031	0.014	

Source: Diagram determined by Sheffield University, England
Van ref: 19

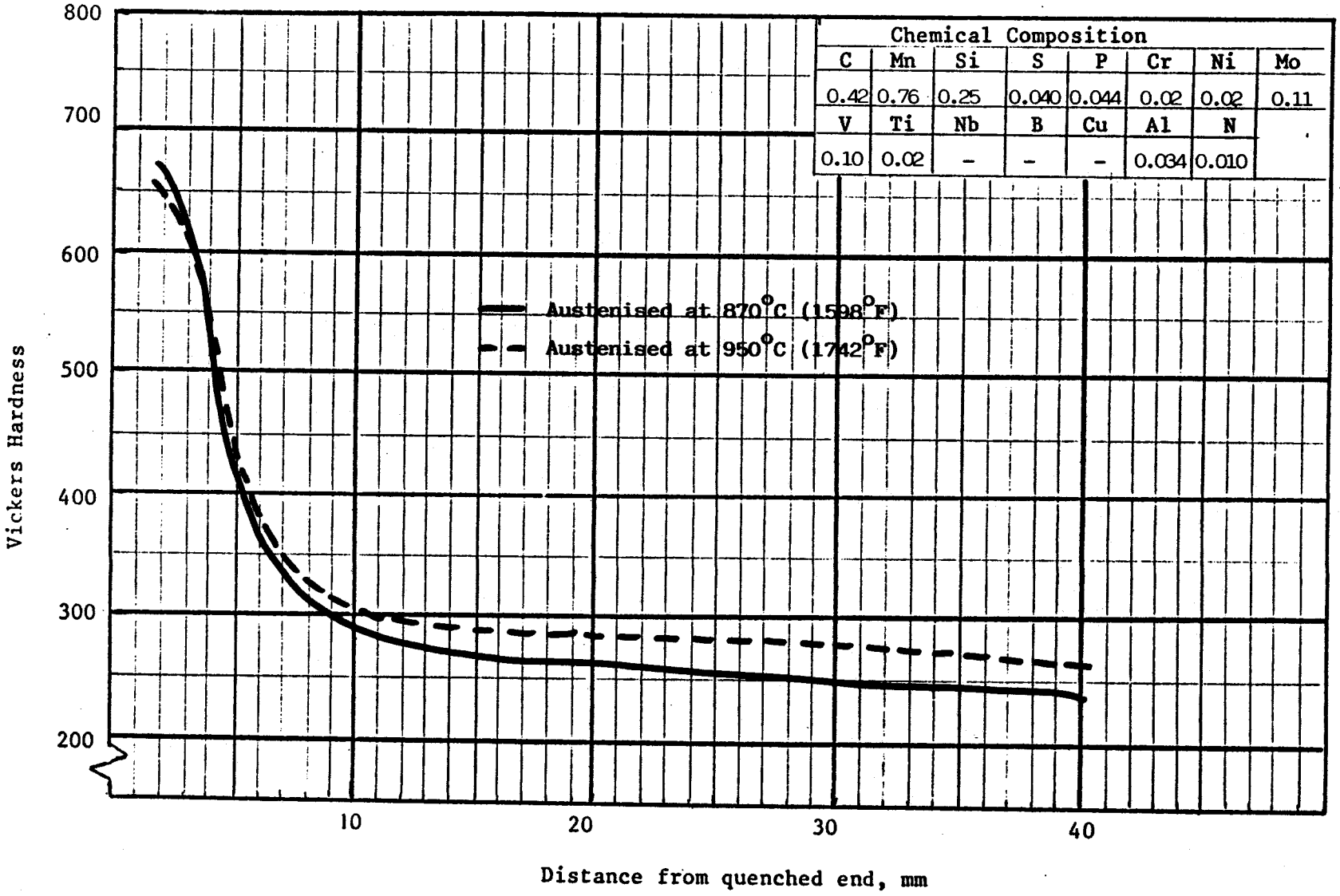
Steel 74



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.42	0.77	0.24	0.034	0.040	0.91	0.03	0.11
V	Ti	Nb	B	Cu	Al	N	
0.02	0.05	-	-	0.02	-	-	

Source: Diagram determined by Sheffield University, England
Van ref: 29

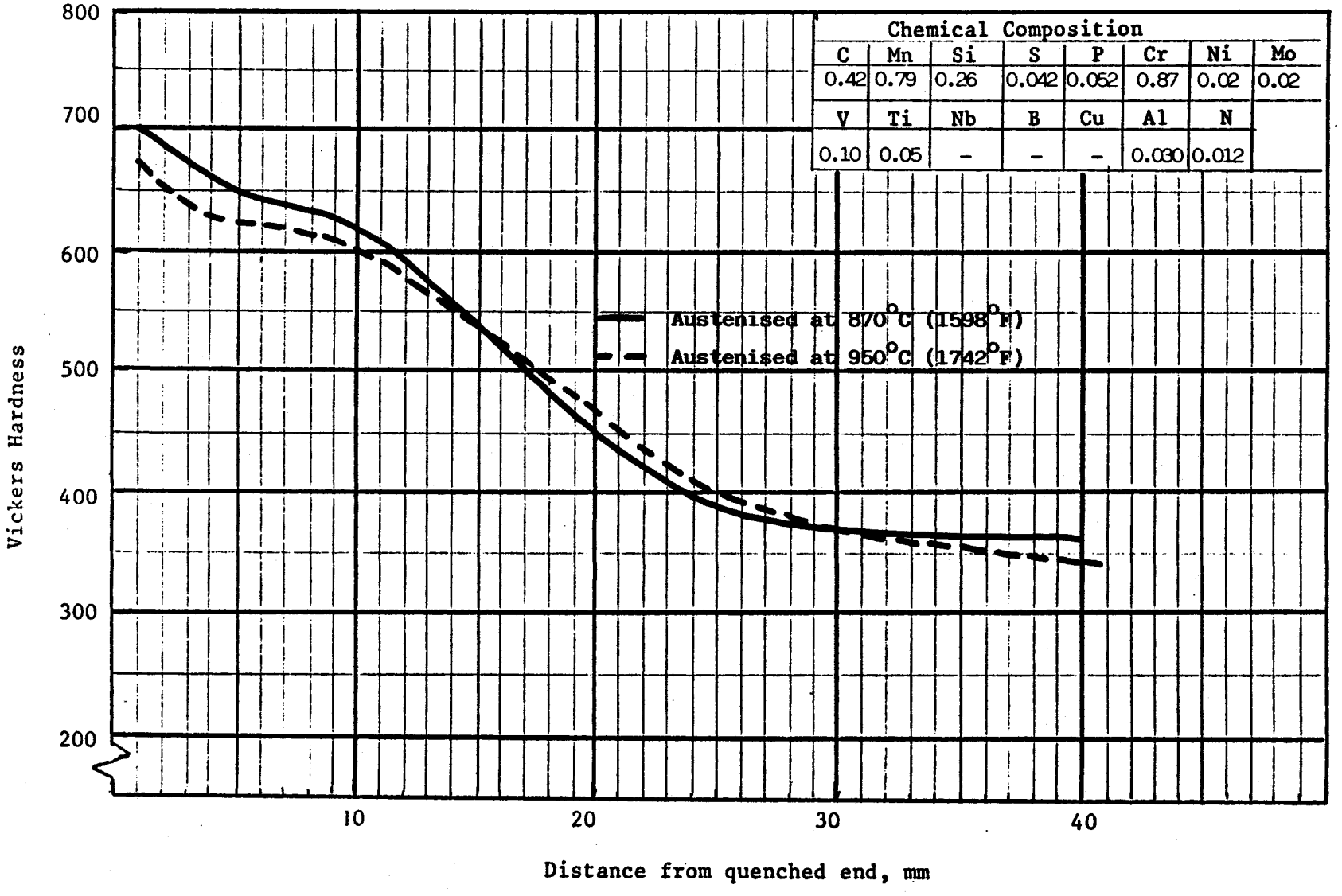
Steel 75



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.42	0.76	0.25	0.040	0.044	0.02	0.02	0.11
V	Ti	Nb	B	Cu	Al	N	
0.10	0.02	-	-	-	0.034	0.010	

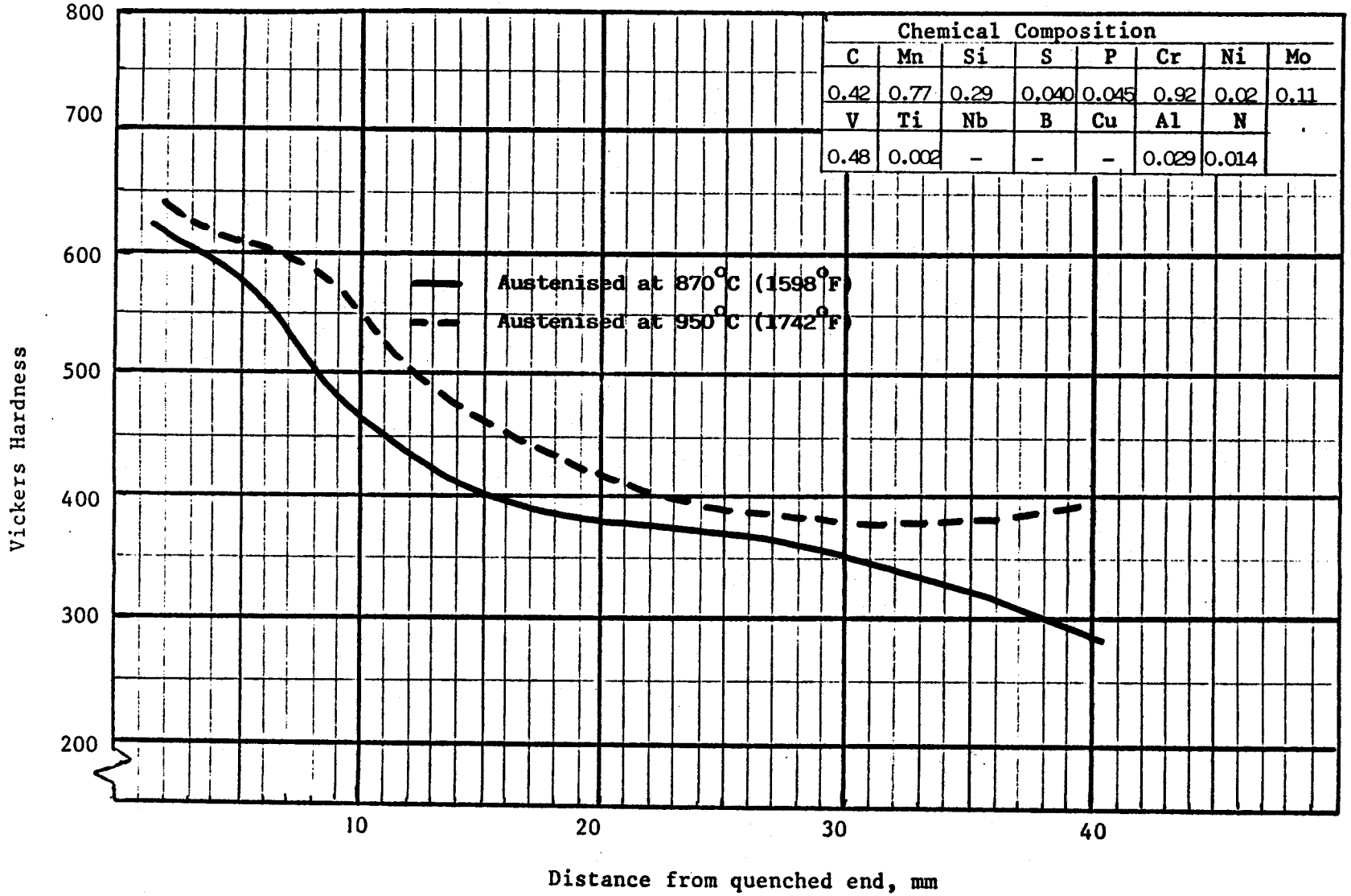
Source: Diagram determined by Sheffield University, England.
Van ref: 16

Steel 76



Source: Diagram determined by Sheffield University, England.
Van ref: 18

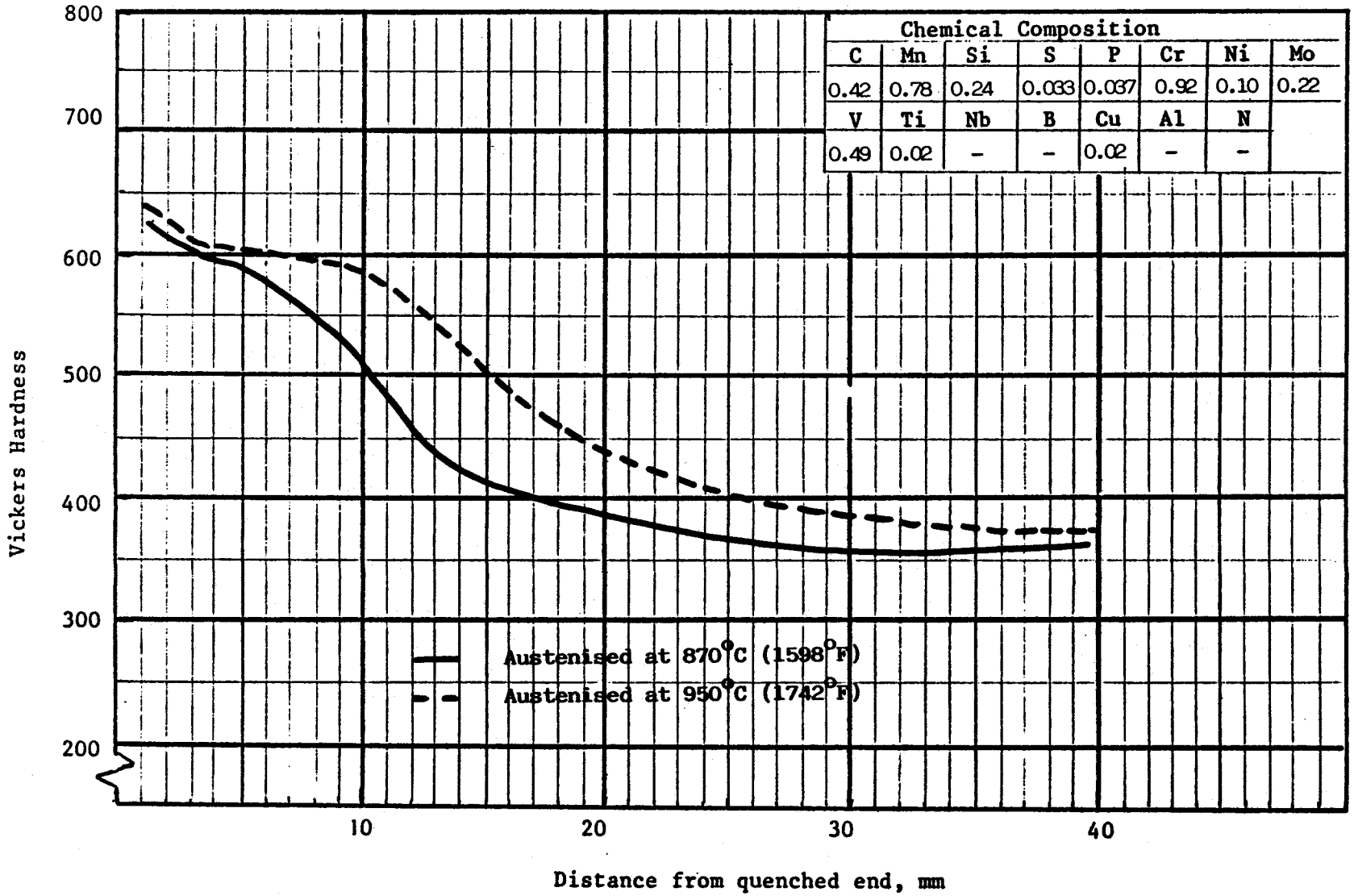
Steel 77



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.42	0.77	0.29	0.040	0.045	0.92	0.02	0.11
V	Ti	Nb	B	Cu	Al	N	
0.48	0.002	–	–	–	0.029	0.014	

Source: Diagram determined by Sheffield University, England.
Van ref: 20

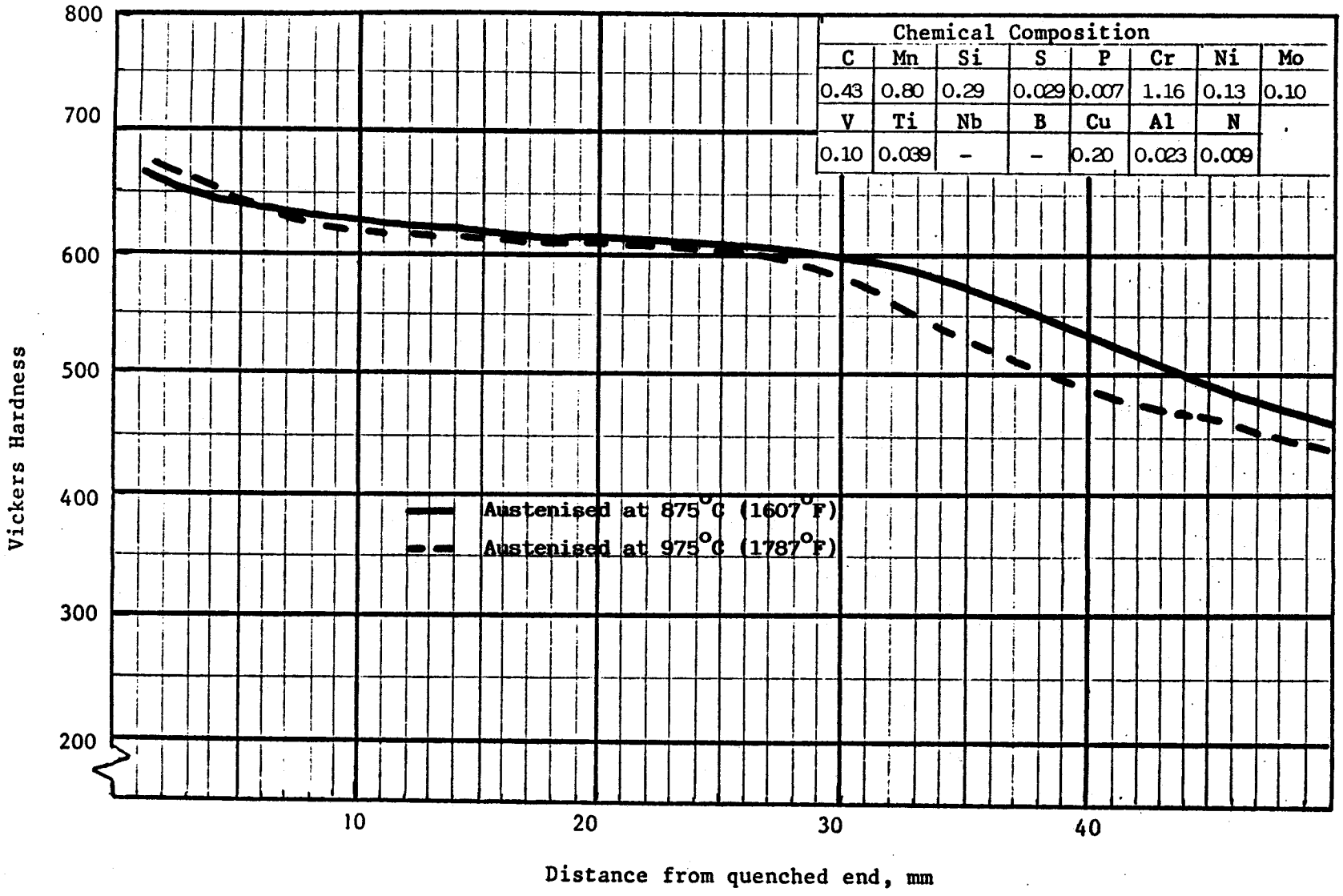
Steel 78



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.42	0.78	0.24	0.033	0.037	0.92	0.10	0.22
V	Ti	Nb	B	Cu	Al	N	
0.49	0.02	-	-	0.02	-	-	

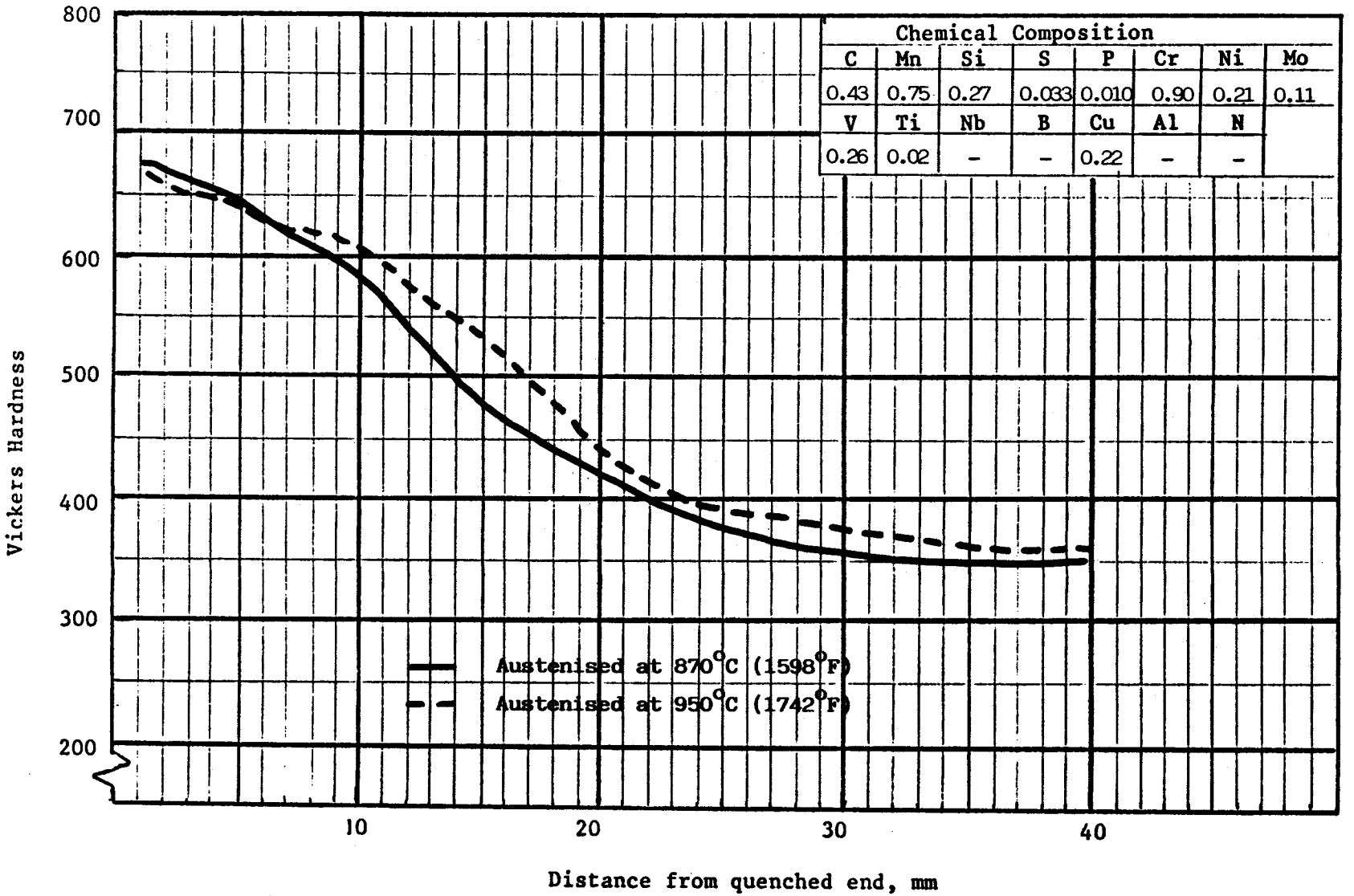
Source: Diagram determined by Sheffield University, England.
Van ref: 28

Steel 79



Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 53

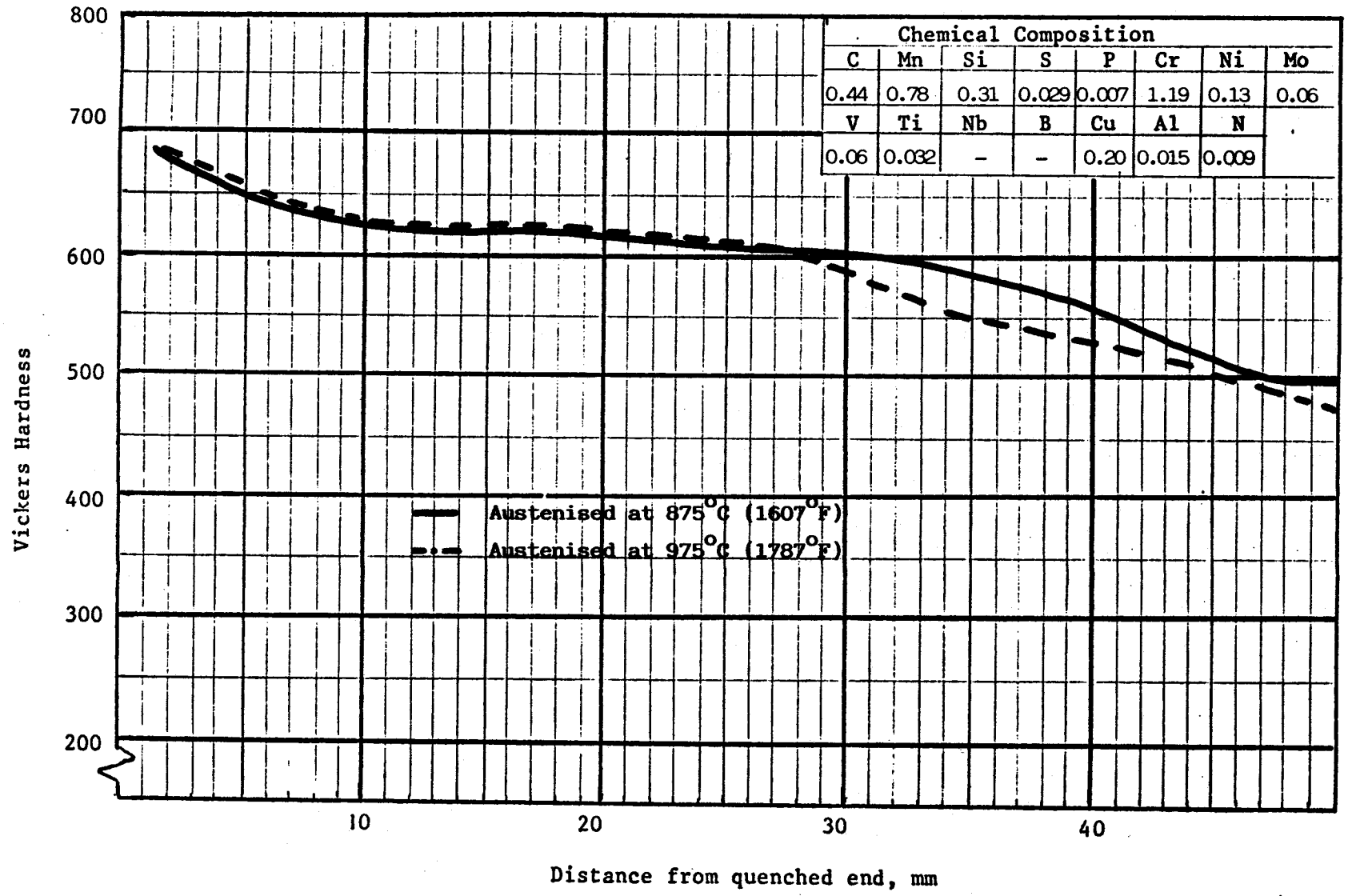
Steel 80



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.43	0.75	0.27	0.033	0.010	0.90	0.21	0.11
V	Ti	Nb	B	Cu	Al	N	
0.26	0.02	-	-	0.22	-	-	

Source: Diagram determined by Sheffield University, England.
Van ref: 30

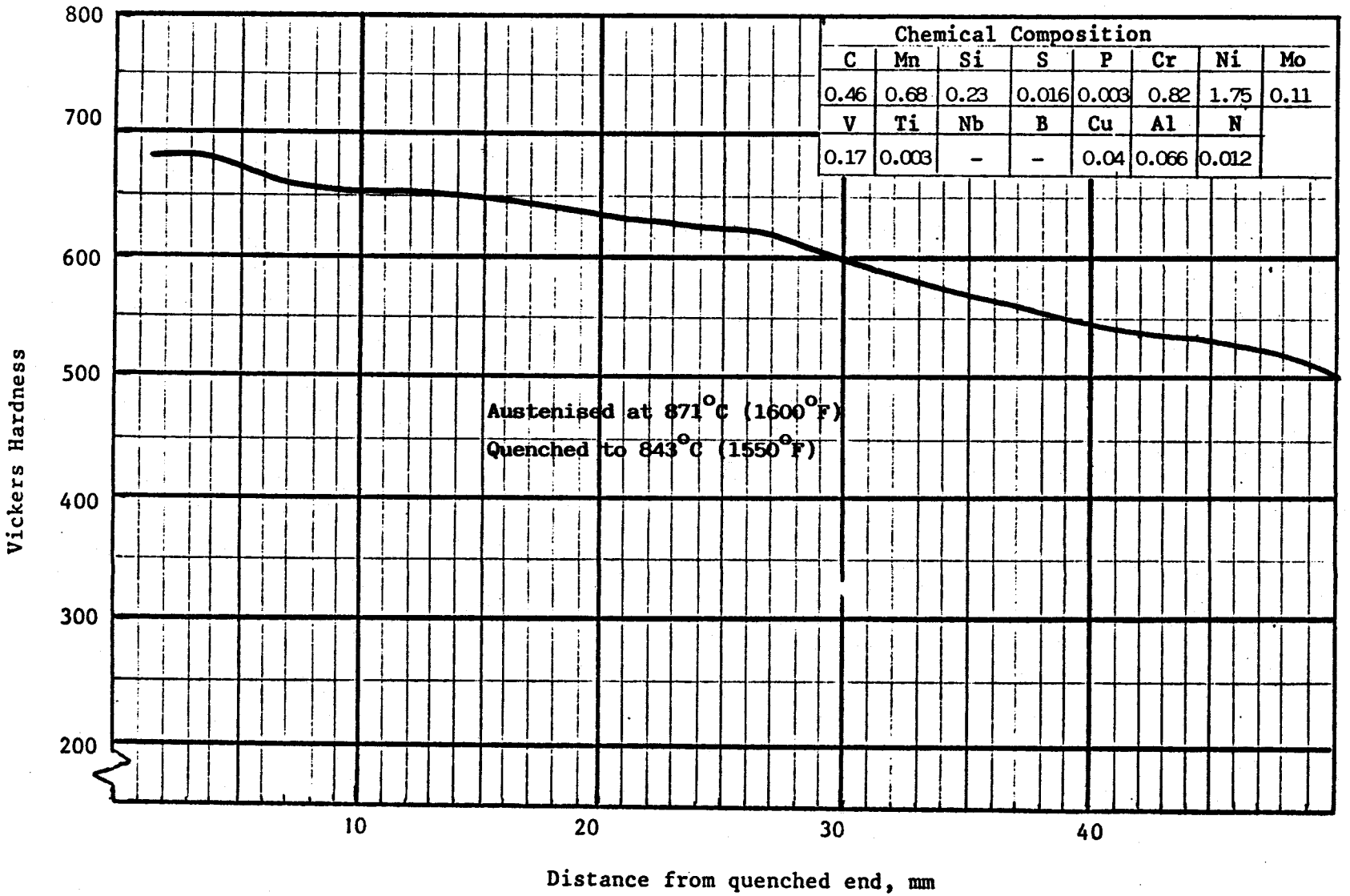
Steel 81



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.44	0.78	0.31	0.029	0.007	1.19	0.13	0.06
V	Ti	Nb	B	Cu	Al	N	
0.06	0.032	-	-	0.20	0.015	0.009	

Source: Diagram determined by Institutet for Metallforskning, Sweden
Van ref: 55

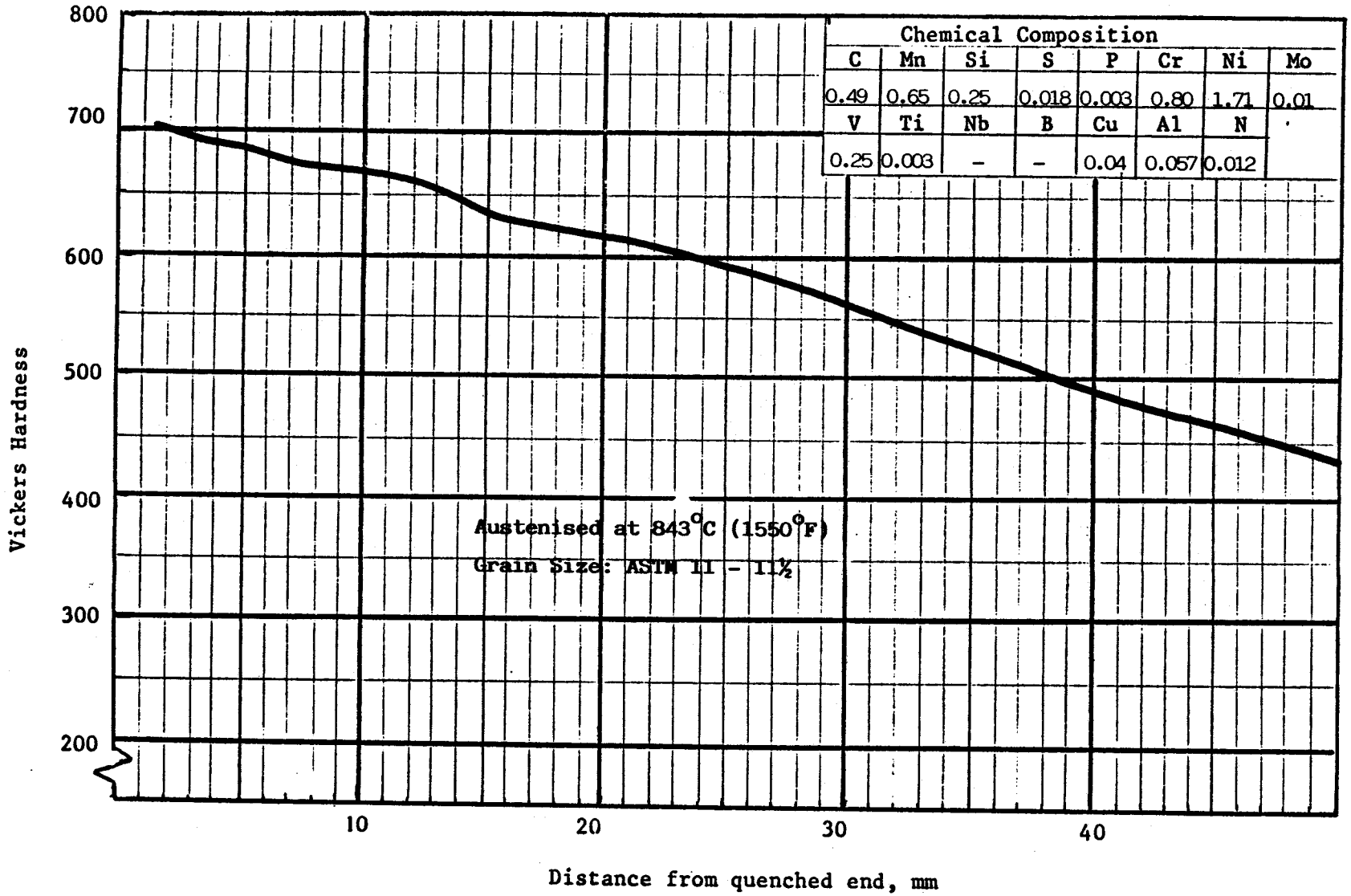
Steel 82



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.46	0.68	0.23	0.016	0.003	0.82	1.75	0.11
V	Ti	Nb	B	Cu	Al	N	
0.17	0.003	-	-	0.04	0.066	0.012	

Source: Foote Mineral Company, U.S.A.
Van ref: 62

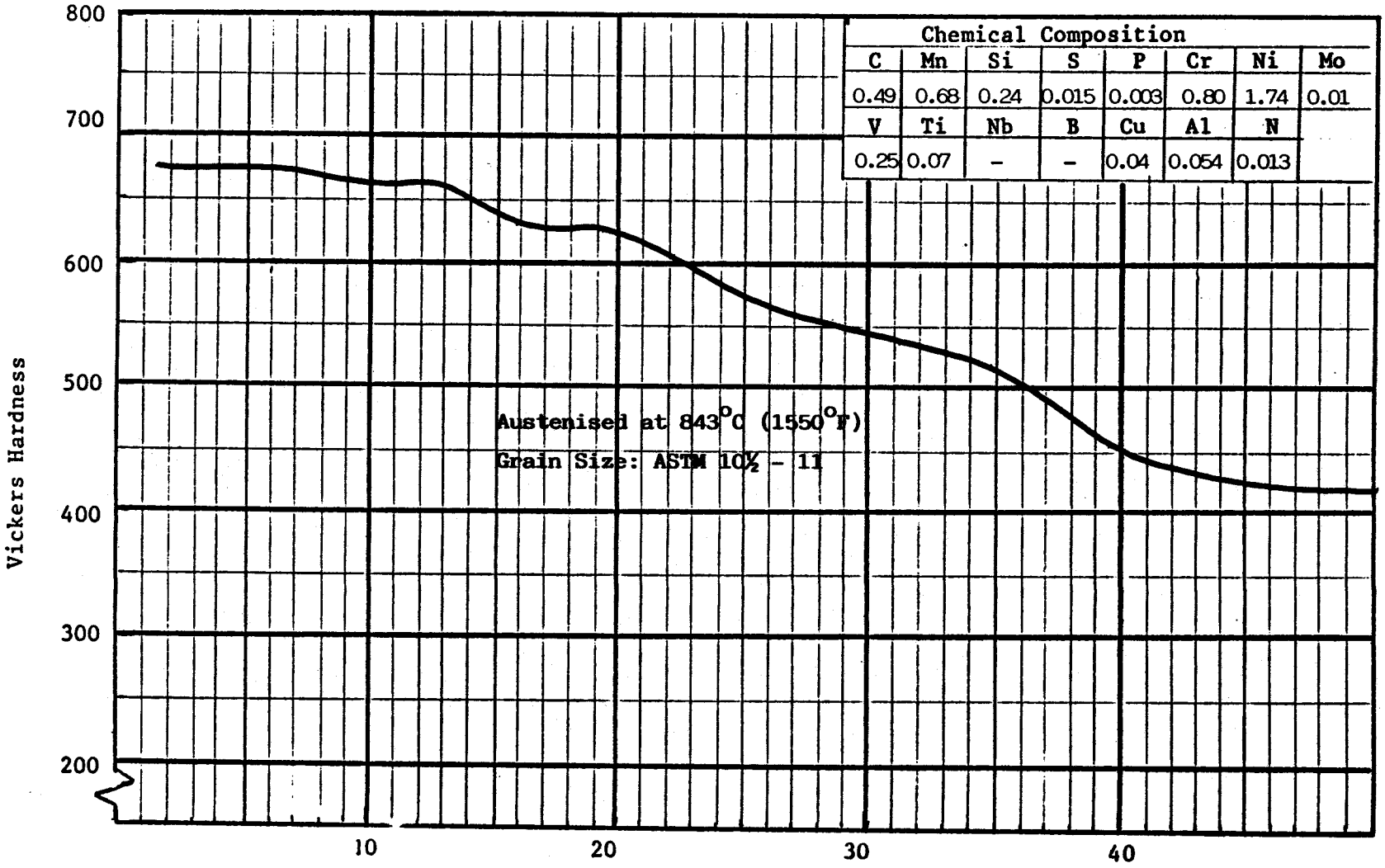
Steel 83



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.49	0.65	0.25	0.018	0.003	0.80	1.71	0.01
V	Ti	Nb	B	Cu	Al	N	
0.25	0.003	–	–	0.04	0.057	0.012	

Source: Foote Mineral Company, U.S.A.
Van ref: 80

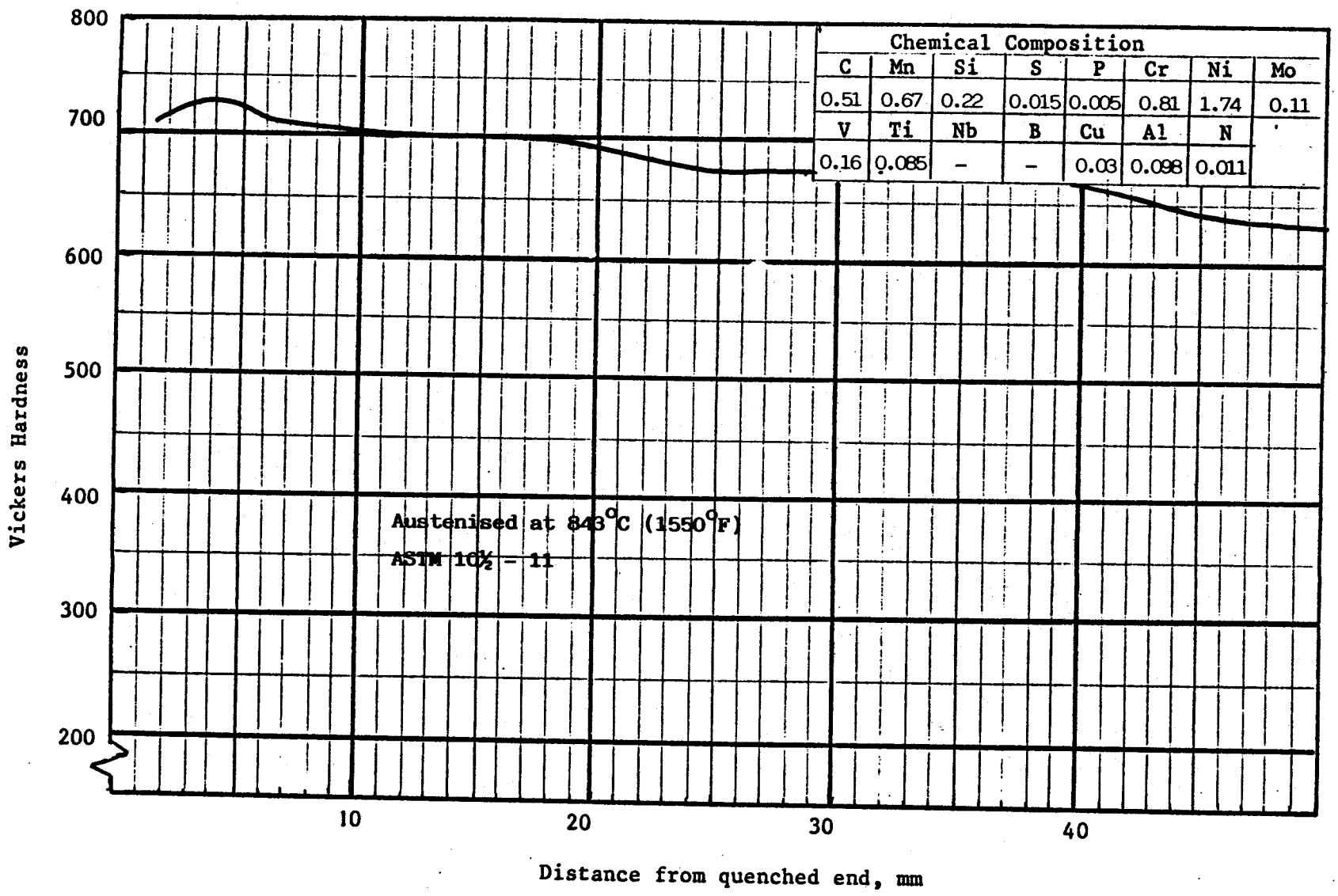
Steel 84



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.49	0.68	0.24	0.015	0.003	0.80	1.74	0.01
V	Ti	Nb	B	Cu	Al	N	
0.25	0.07	-	-	0.04	0.054	0.013	

Source: Foote Mineral Company, U.S.A.
Van ref: 78

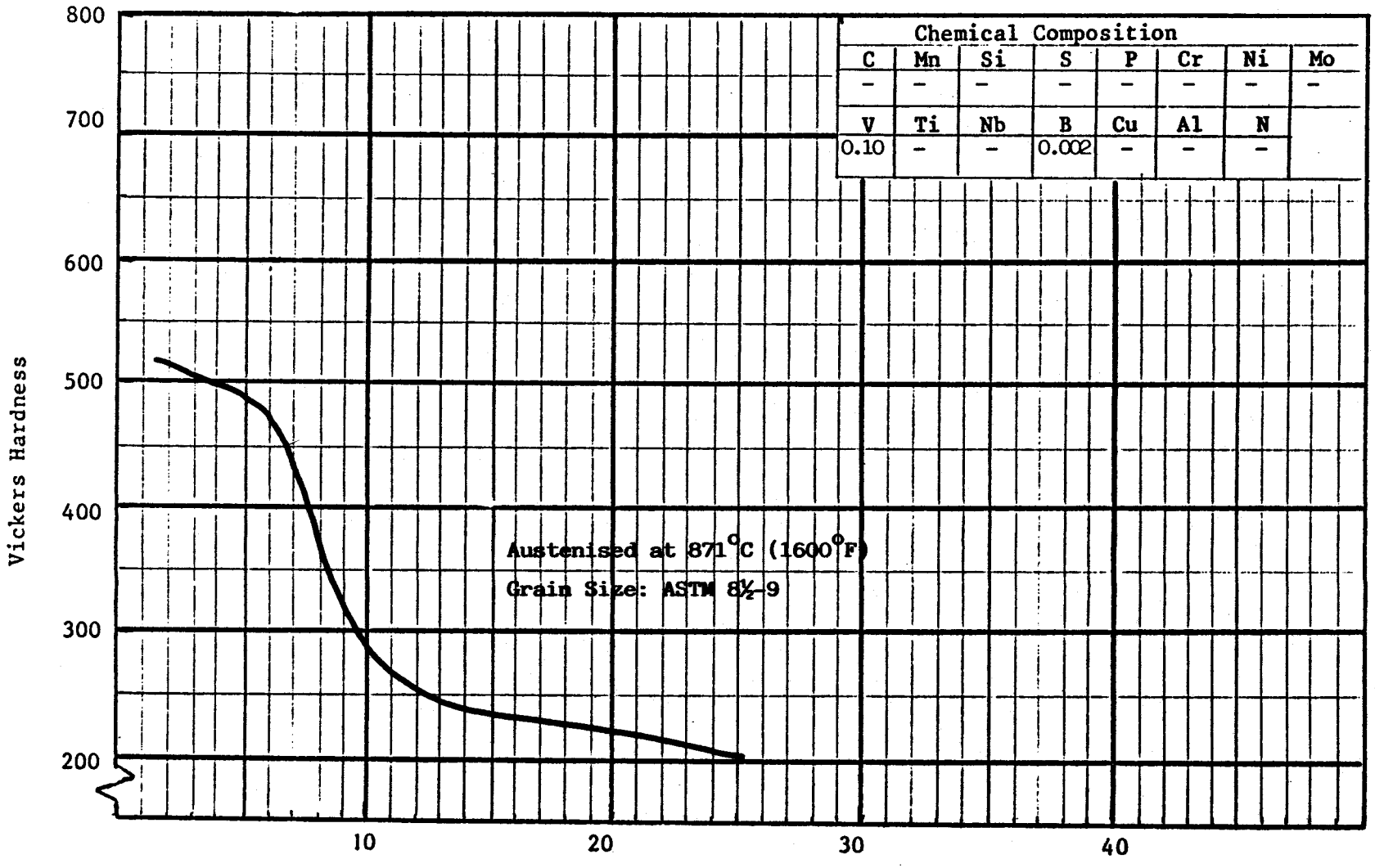
Steel 85



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.51	0.67	0.22	0.015	0.005	0.81	1.74	0.11
V	Ti	Nb	B	Cu	Al	N	
0.16	0.085	–	–	0.03	0.098	0.011	

Source: Foote Mineral Company, U.S.A.
Van ref: 79

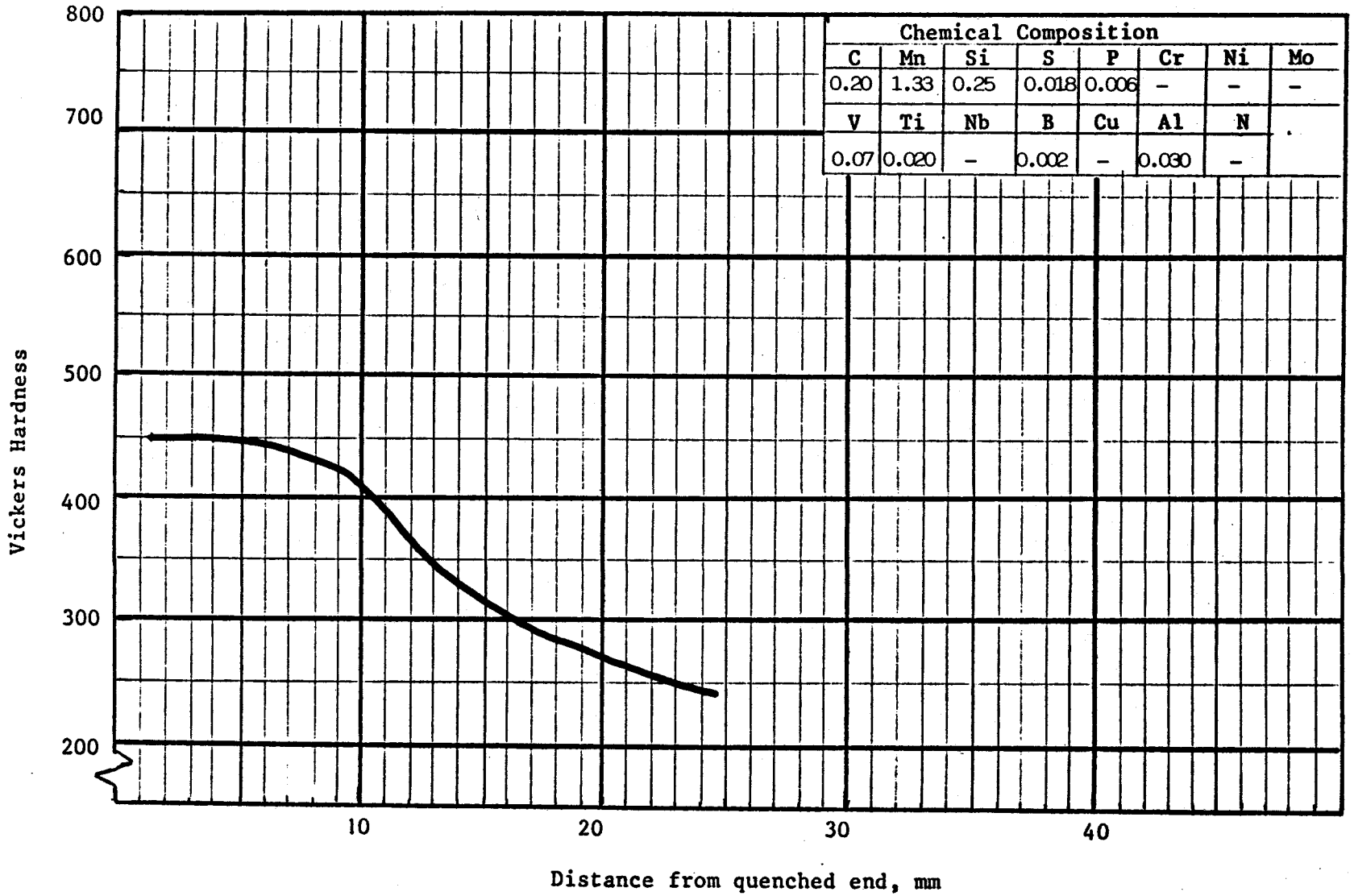
Steel 86



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
-	-	-	-	-	-	-	-
V	Ti	Nb	B	Cu	Al	N	
0.10	-	-	0.002	-	-	-	

Source: Diagram determined by Foote Mineral Company, USA.
Van ref: 34

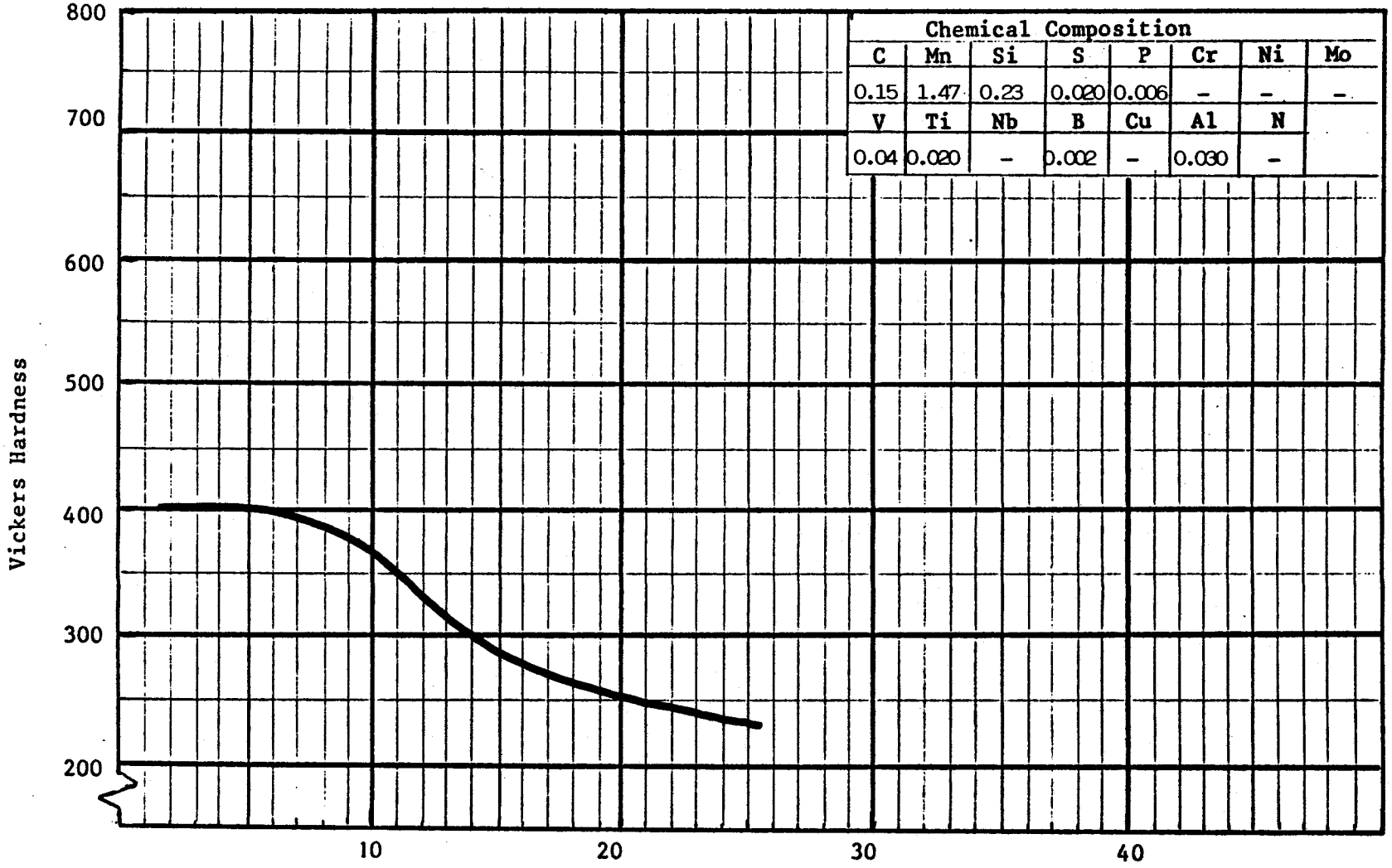
Steel 87



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.20	1.33	0.25	0.018	0.006	–	–	–
V	Ti	Nb	B	Cu	Al	N	
0.07	0.020	–	0.002	–	0.030	–	

Source: M. K. Koul and R. B. G. Yeo, Metals Engineering Quarterly, August 1972.
Van ref: 87

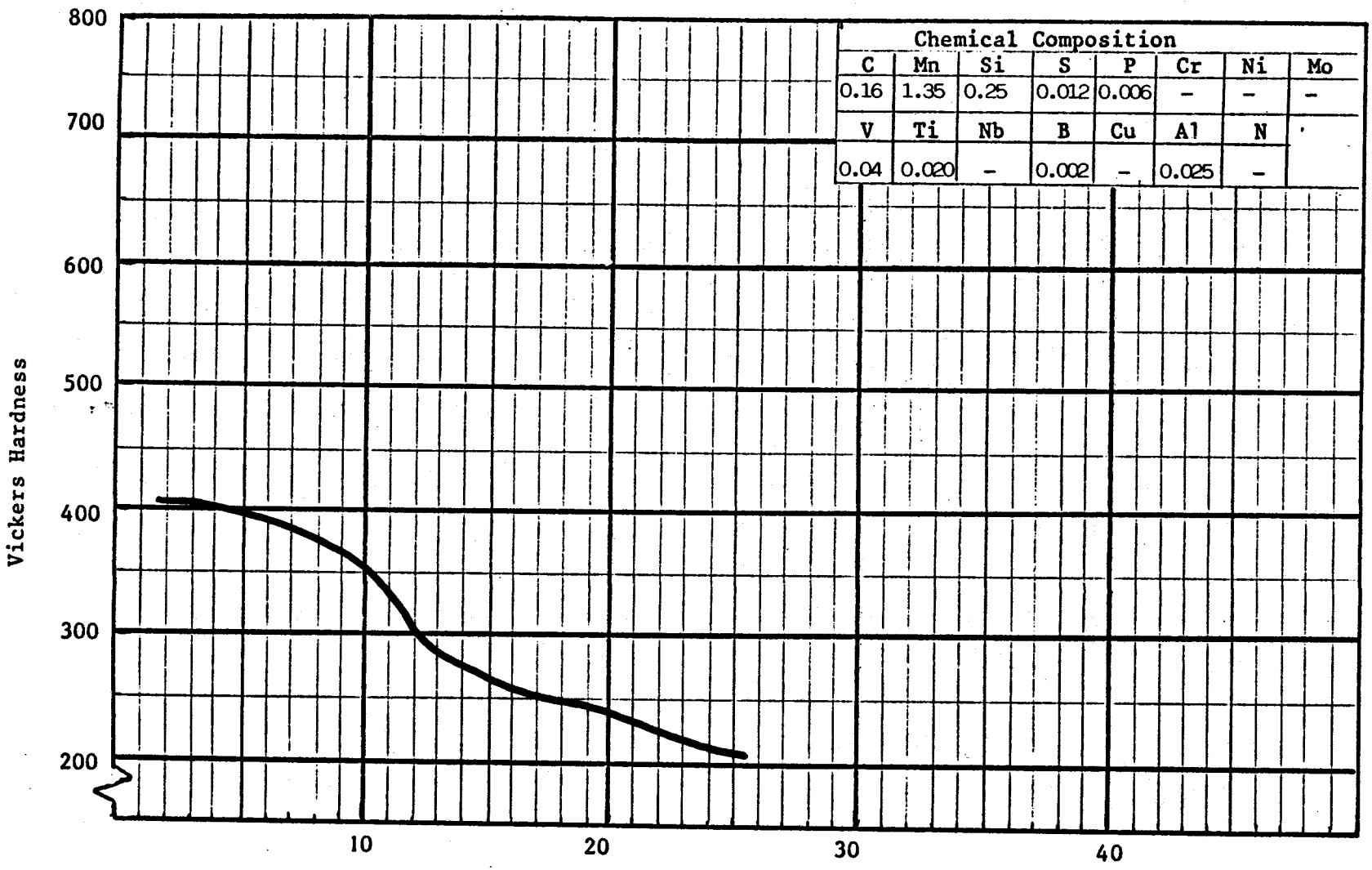
Steel 88



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.15	1.47	0.23	0.020	0.006	-	-	-
V	Ti	Nb	B	Cu	Al	N	
0.04	0.020	-	0.002	-	0.030	-	

Source: M. K. Koul and R. B. G. Yeo, Metals Engineering Quarterly, August 1972
Van ref: 86

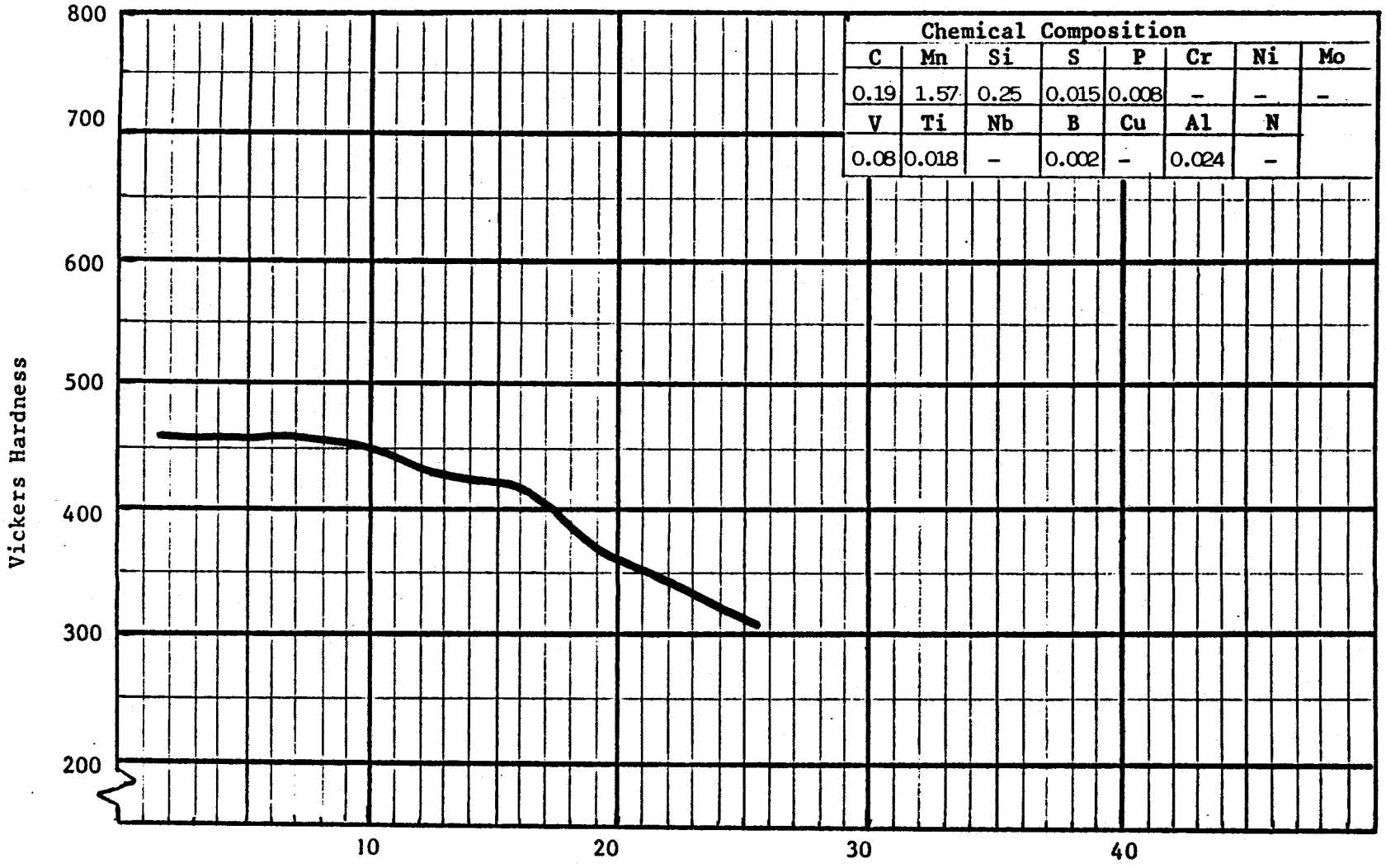
Steel 89



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.16	1.35	0.25	0.012	0.006	–	–	–
V	Ti	Nb	B	Cu	Al	N	
0.04	0.020	–	0.002	–	0.025	–	

Source: M. K. Koul and R. B. G. Yeo, Metals Engineering Quarterly, August 1972.
Van ref: 85

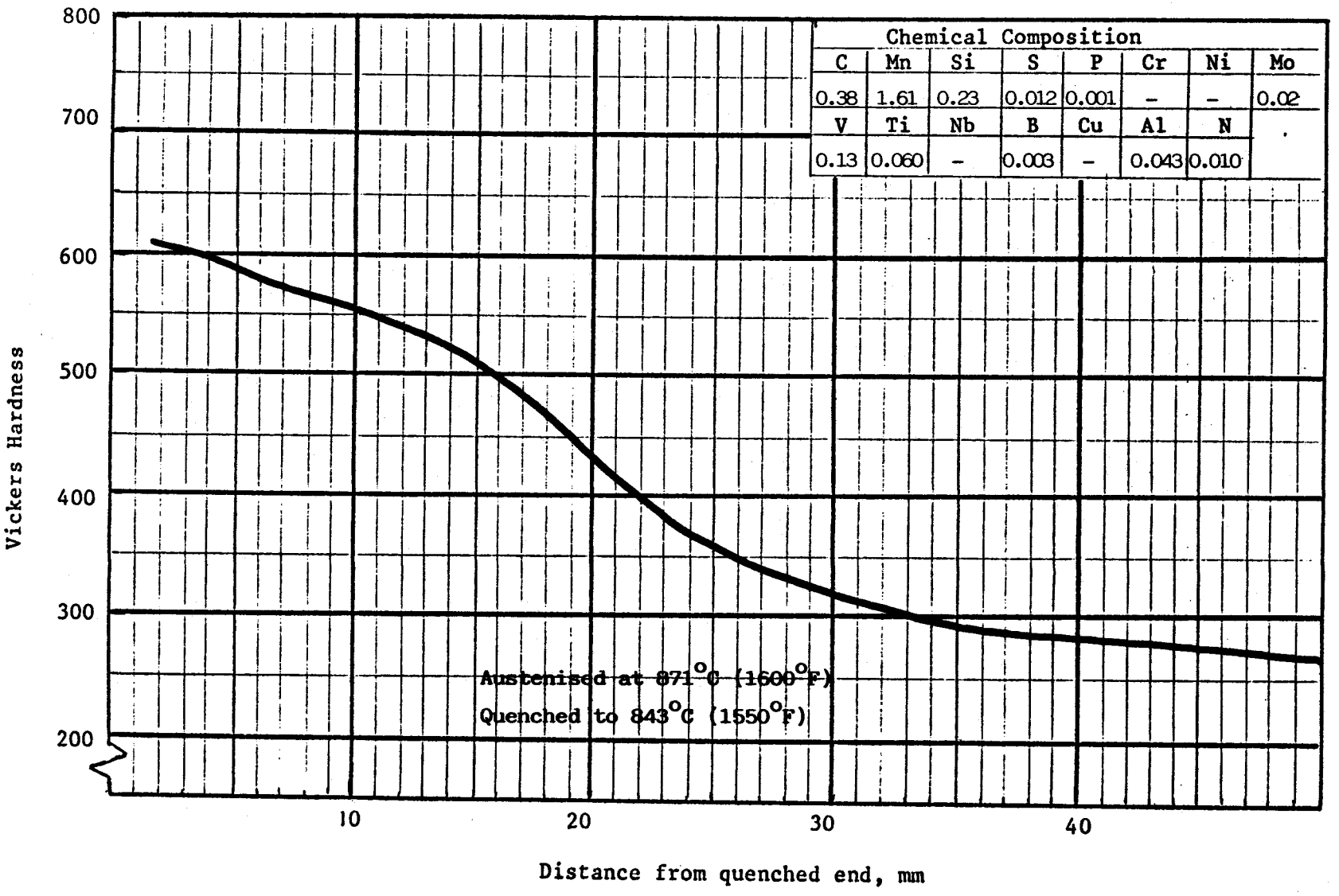
Steel 90



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.19	1.57	0.25	0.015	0.008	-	-	-
V	Ti	Nb	B	Cu	Al	N	
0.08	0.018	-	0.002	-	0.024	-	

Source: M. K. Koul and R. B. G. Yeo, Metals Engineering Quarterly, August 1972
Van ref: 88

Steel 91

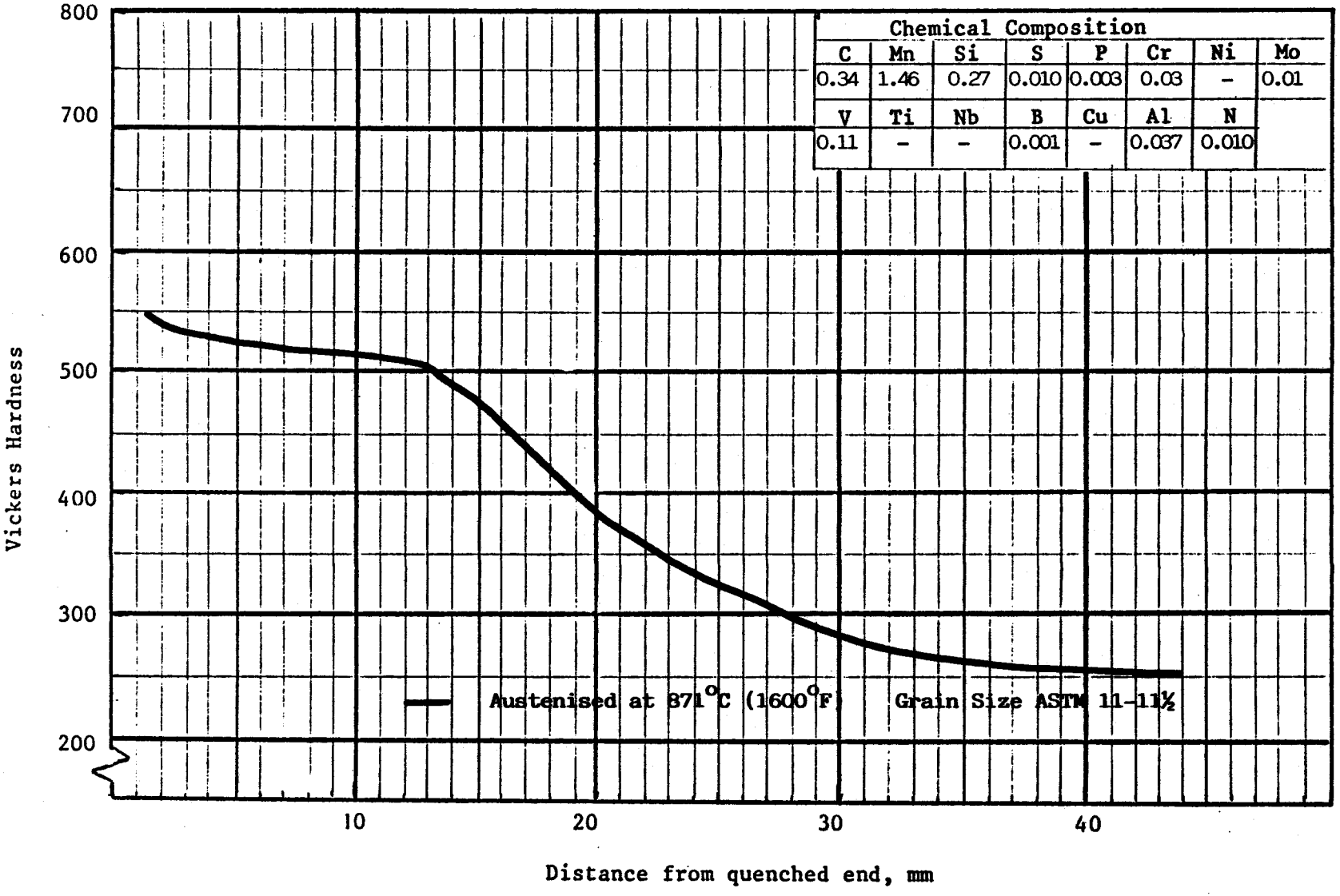


Chemical Composition

C	Mn	Si	S	P	Cr	Ni	Mo
0.38	1.61	0.23	0.012	0.001	–	–	0.02
V	**Ti**	**Nb**	**B**	**Cu**	**Al**	**N**	
0.13	0.060	–	0.003	–	0.043	0.010	

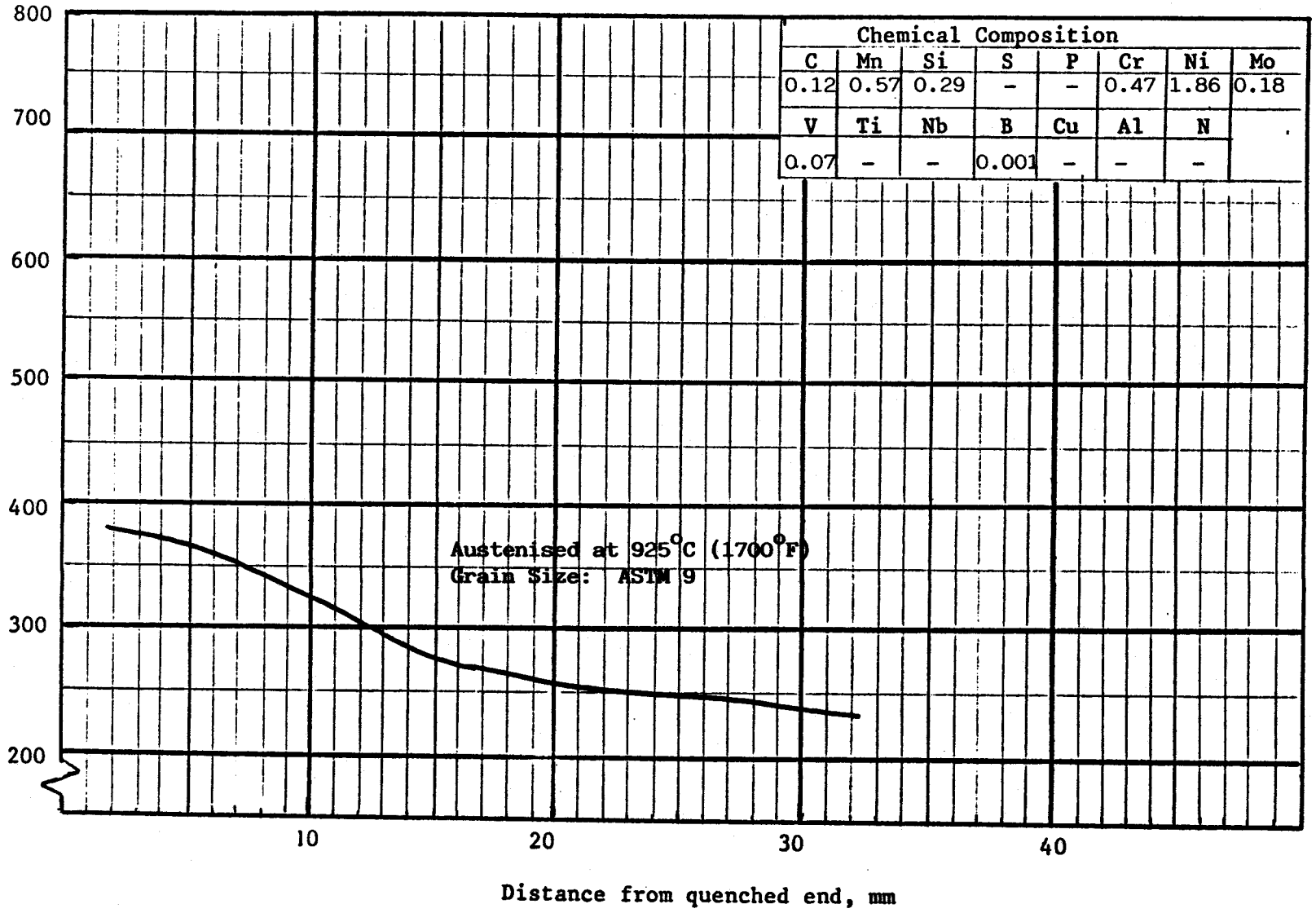
Source: Fotte Mineral Company, U.S.A.
Van ref: 59

Steel 92



Source: Diagram determined by Foote Mineral Company, USA.
Van ref: 32

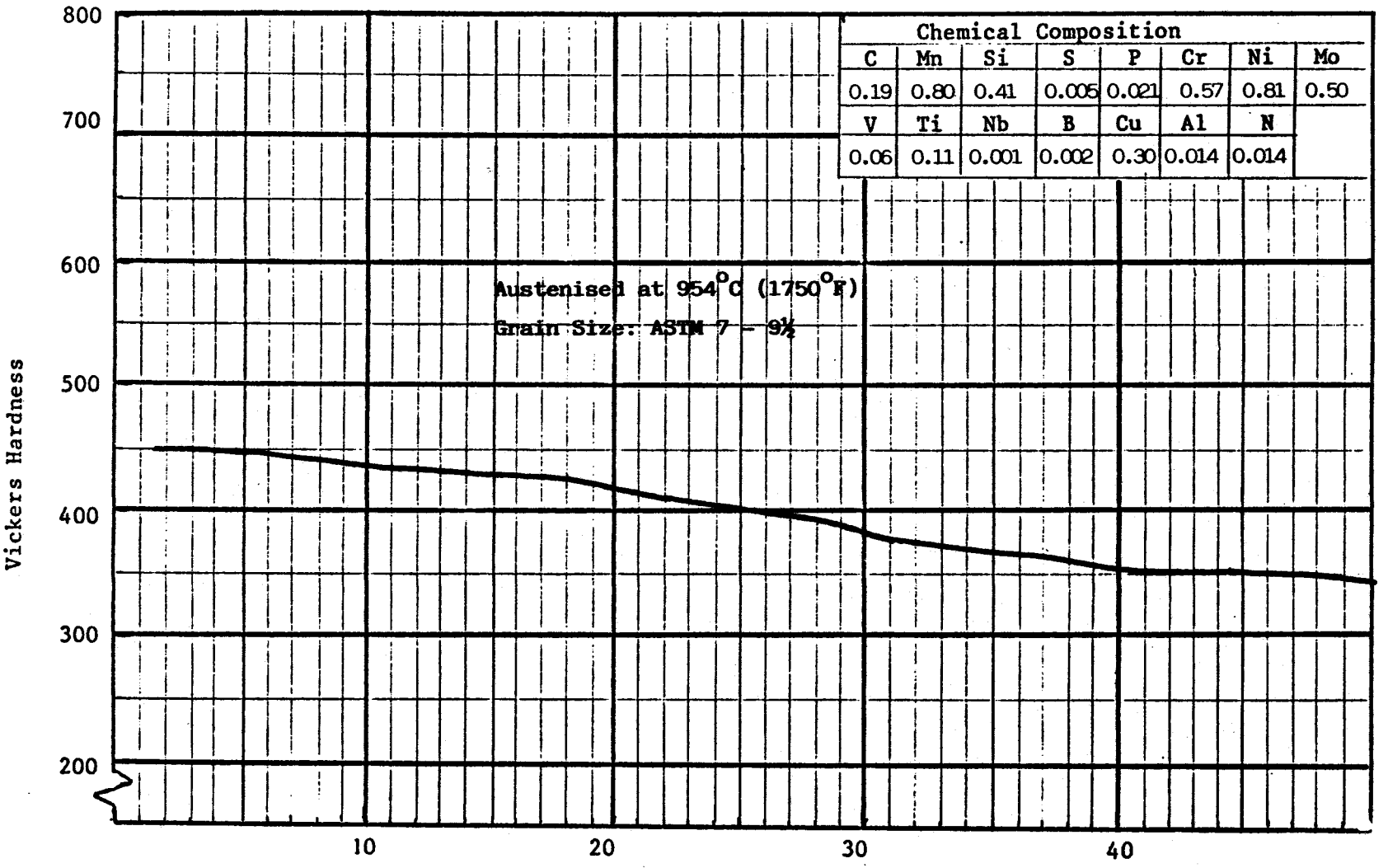
Steel 93



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.12	0.57	0.29	-	-	0.47	1.86	0.18
V	Ti	Nb	B	Cu	Al	N	
0.07	-	-	0.001	-	-	-	

Source: Atlas of Isothermal and Cooling Transformation Diagrams, ASM, 1977
Van ref: 3

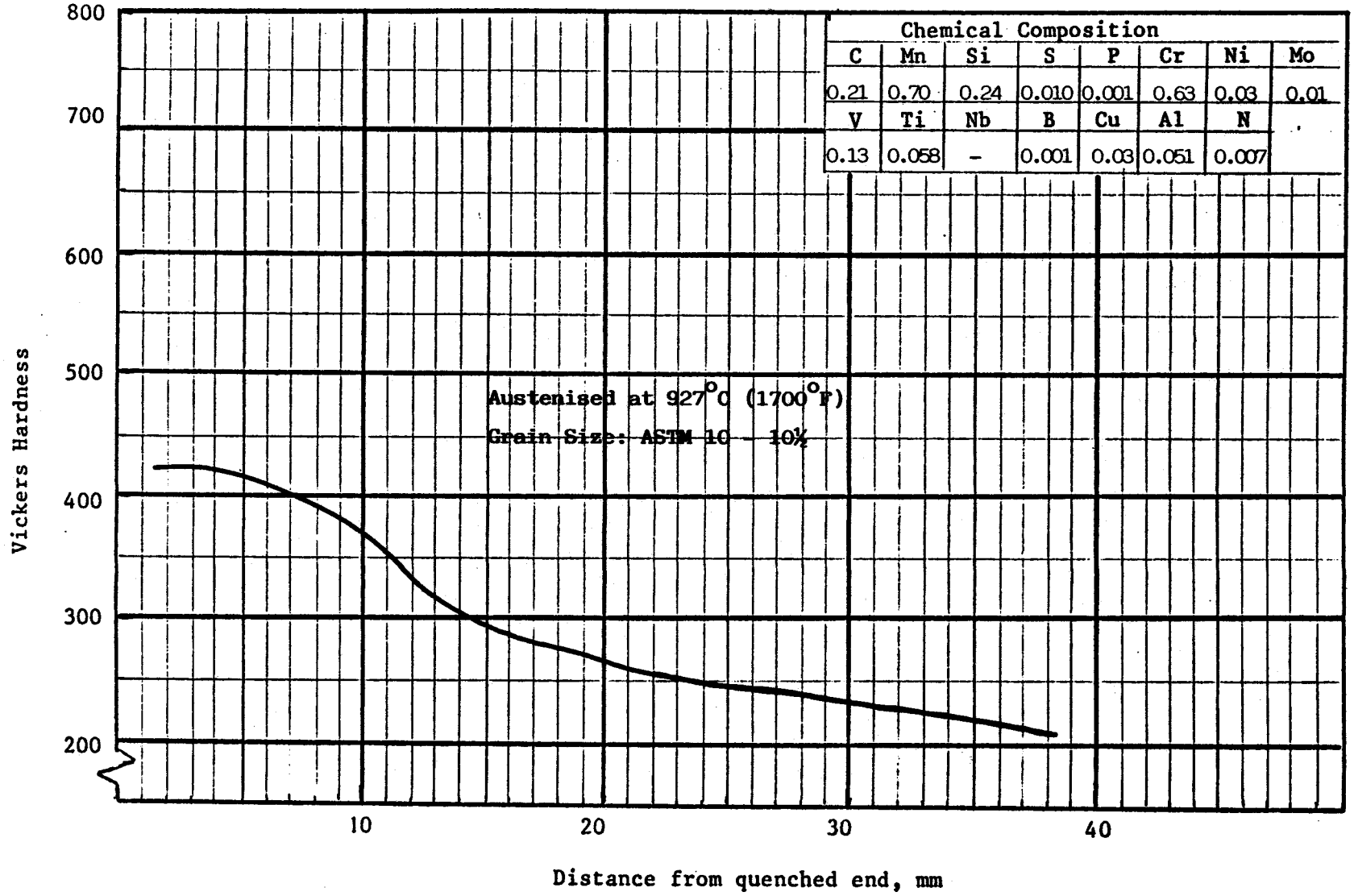
Steel 94



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.19	0.80	0.41	0.005	0.021	0.57	0.81	0.50
V	Ti	Nb	B	Cu	Al	N	
0.06	0.11	0.001	0.002	0.30	0.014	0.014	

Source: Foote Mineral Company, U.S.A.
Van ref: 63

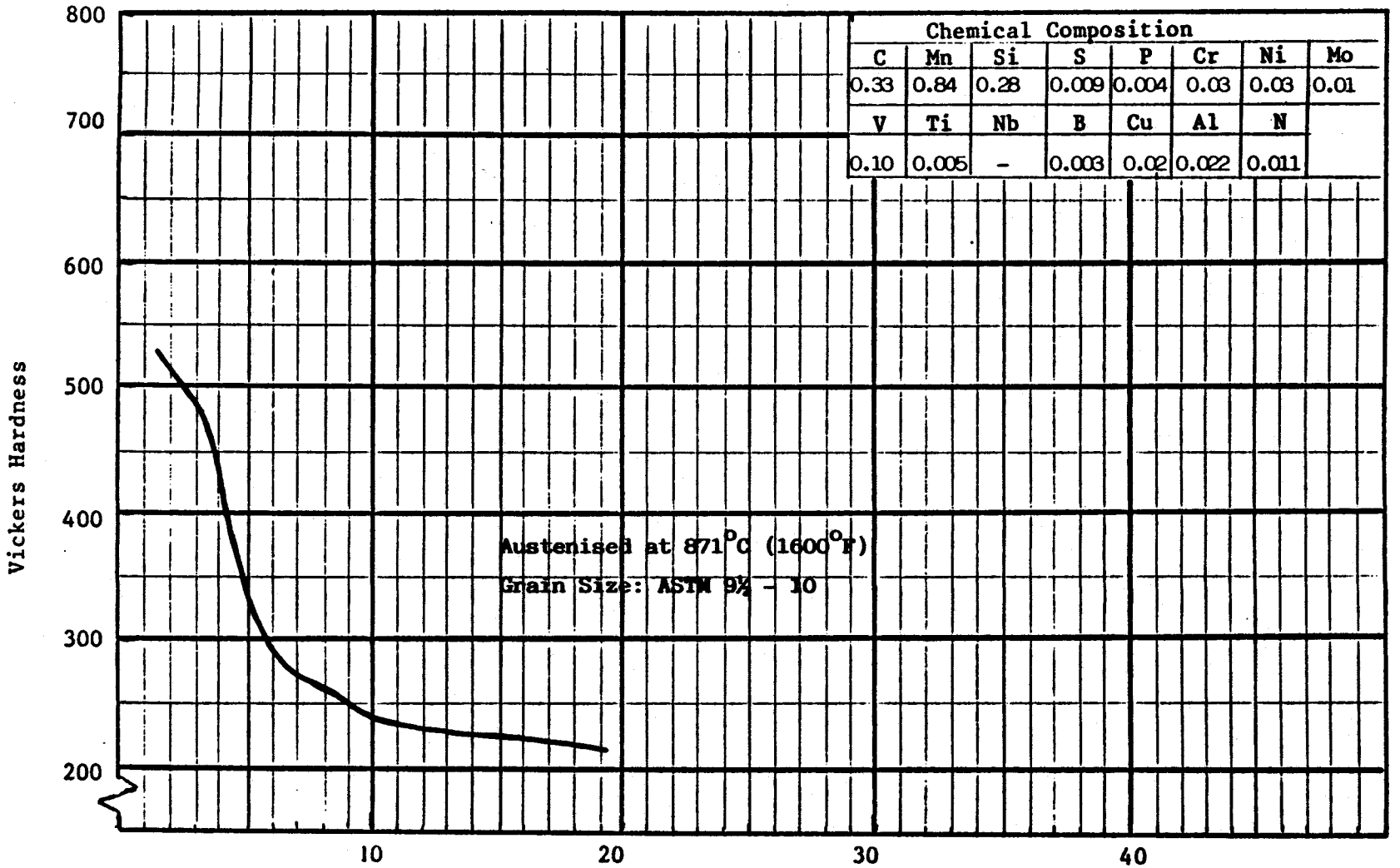
Steel 95



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.21	0.70	0.24	0.010	0.001	0.63	0.03	0.01
V	Ti	Nb	B	Cu	Al	N	
0.13	0.058	–	0.001	0.03	0.051	0.007	

Source: Foote Mineral Company, U.S.A.
Van ref: 68

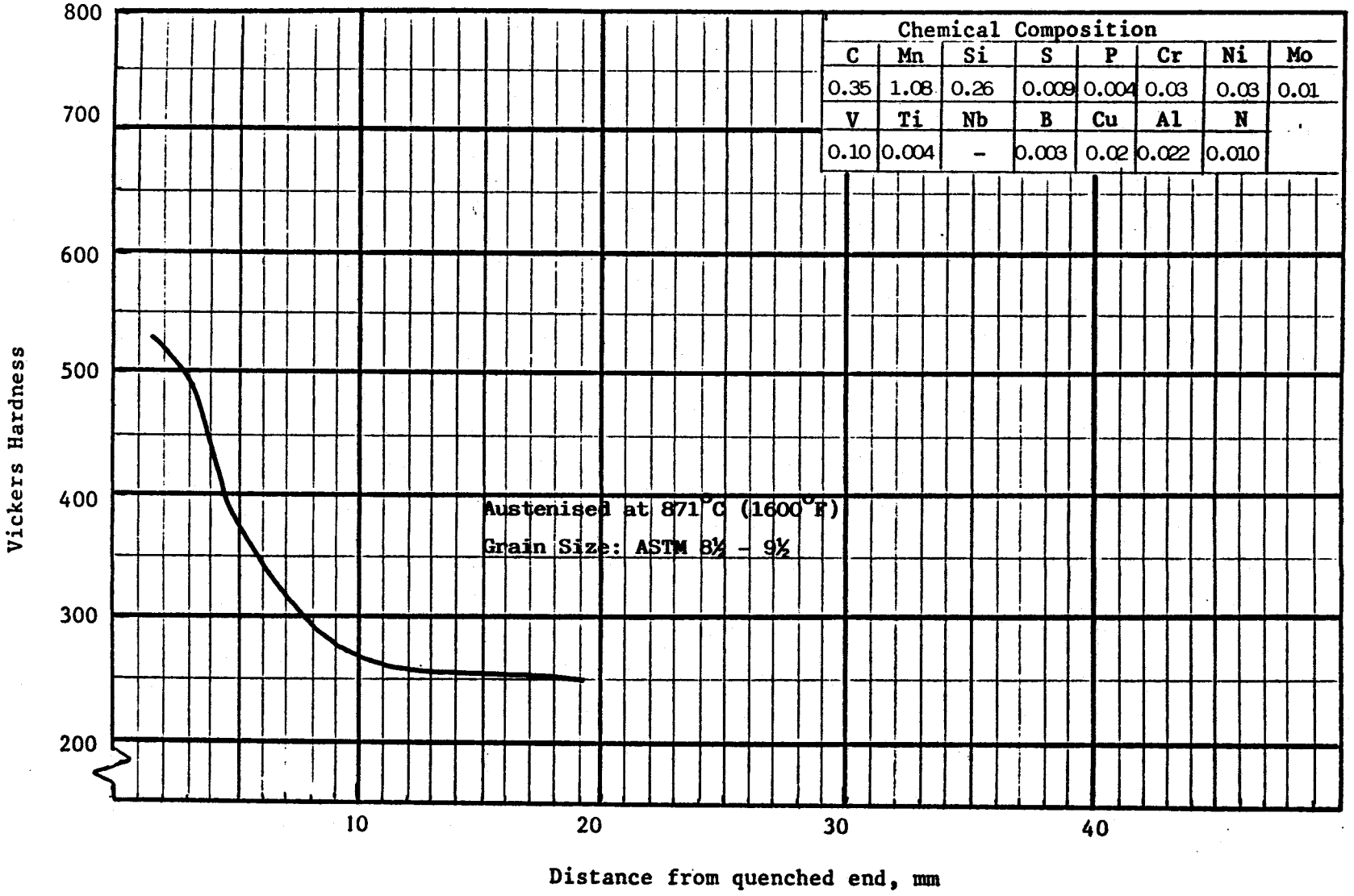
Steel 96



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.33	0.84	0.28	0.009	0.004	0.03	0.03	0.01
V	Ti	Nb	B	Cu	Al	N	
0.10	0.005	-	0.003	0.02	0.022	0.011	

Source: Foote Mineral Company, U.S.A.
Van ref: 66

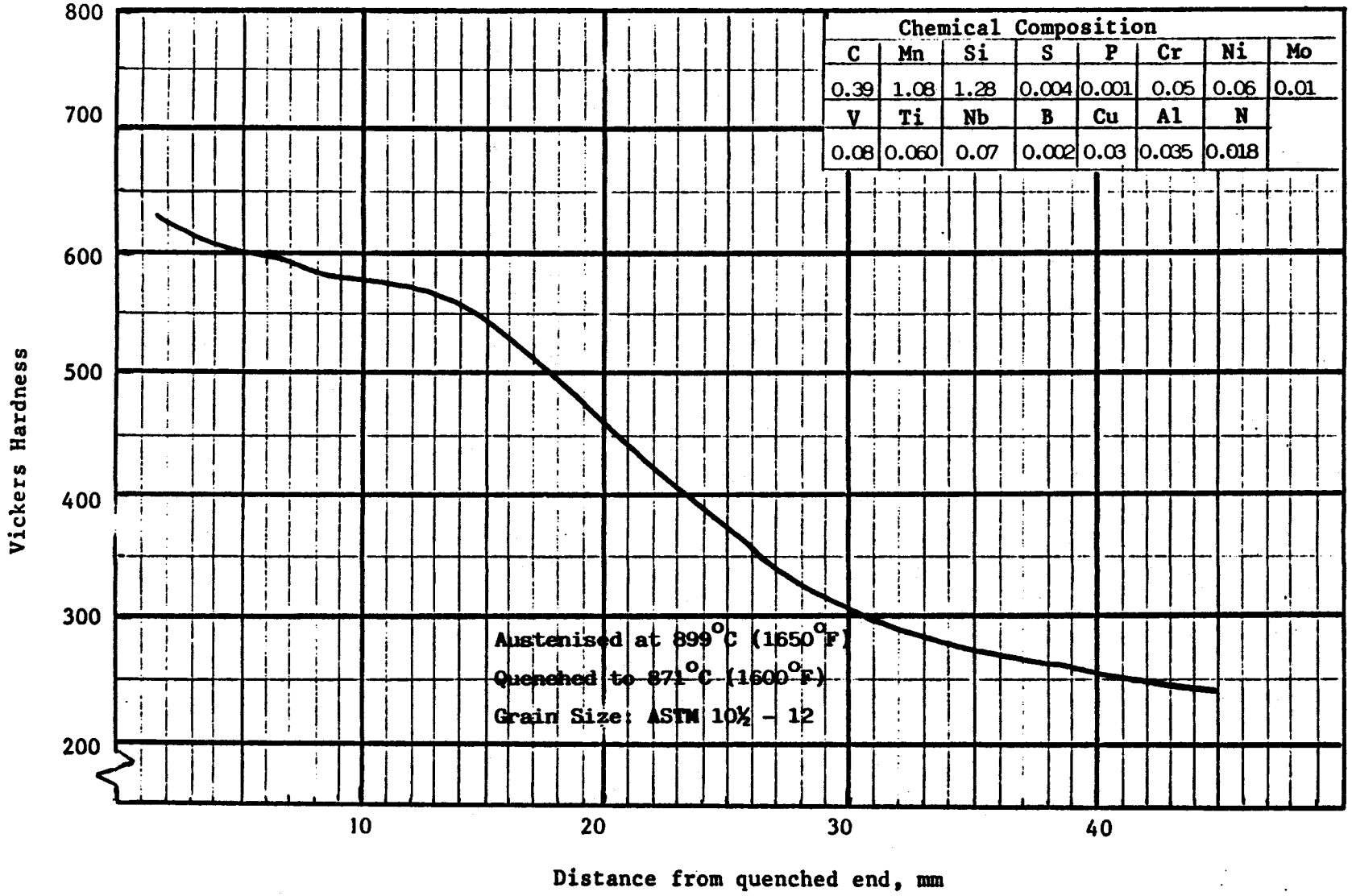
Steel 97



Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.35	1.08	0.26	0.009	0.004	0.03	0.03	0.01
V	Ti	Nb	B	Cu	Al	N	
0.10	0.004	-	0.003	0.02	0.022	0.010	

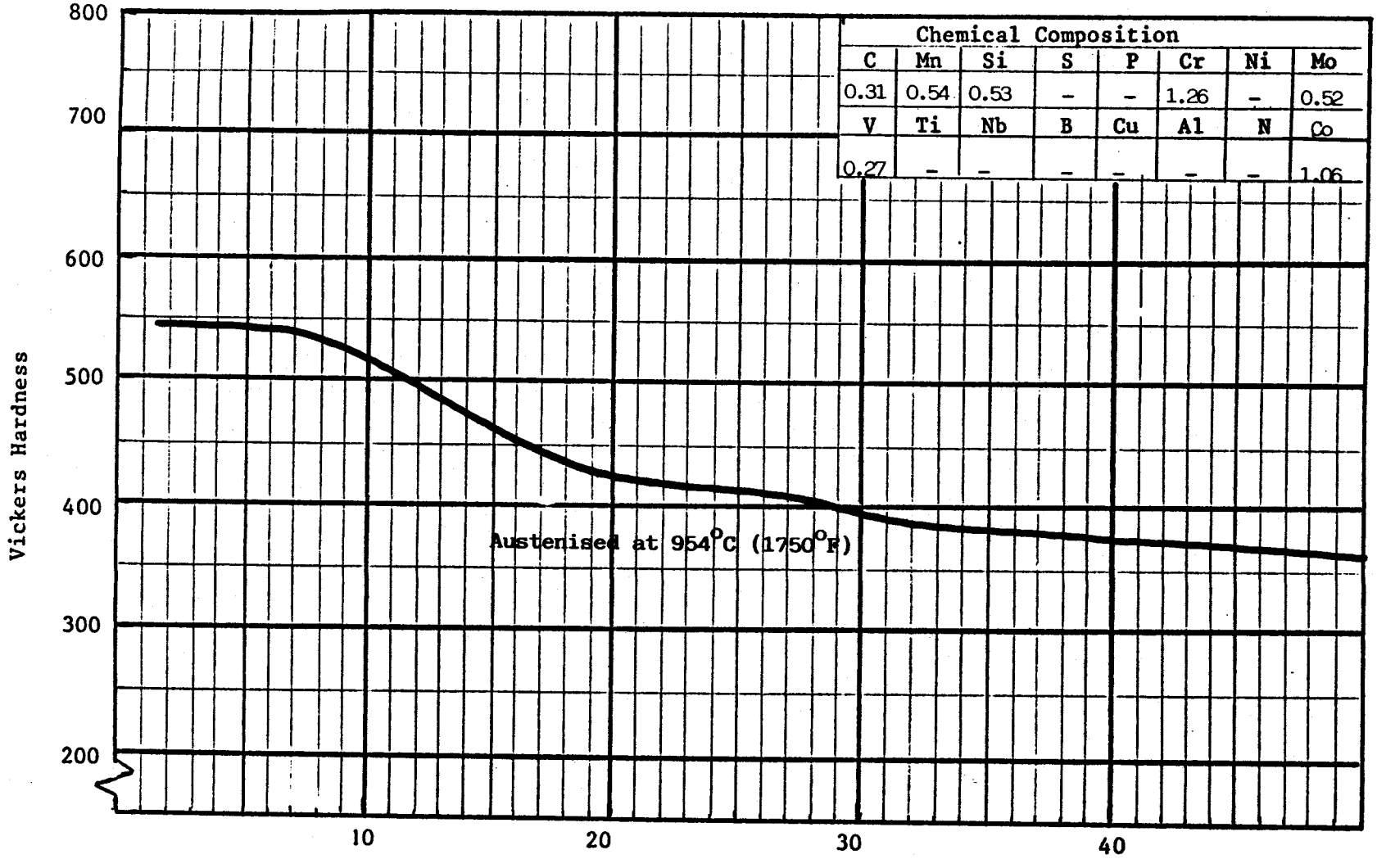
Source: Foote Mineral Company, U.S.A.
Van ref: 67

Steel 98



Source: Foote Mineral Company, U.S.A.
Van ref: 61

Steel 99

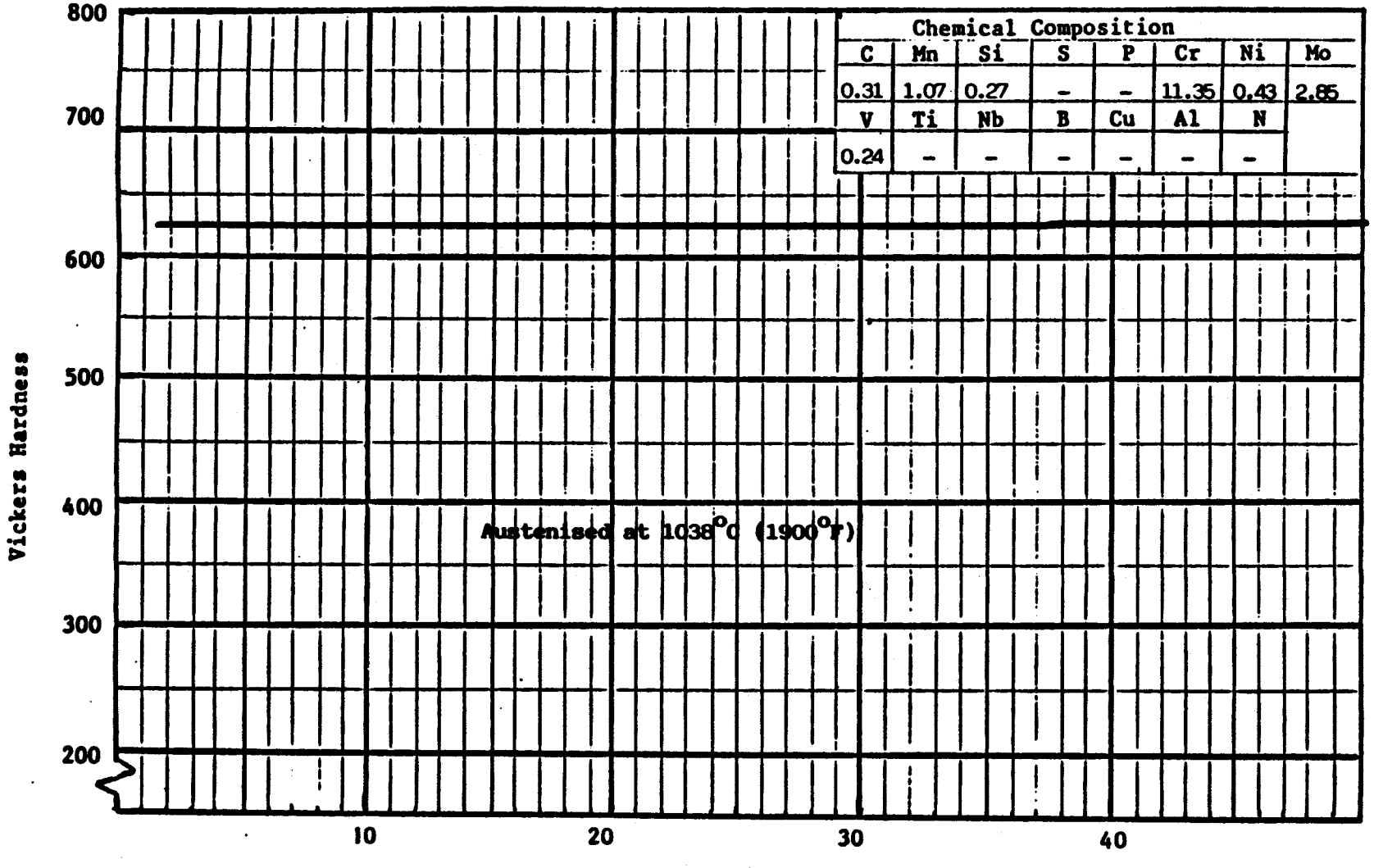


Chemical Composition							
C	Mn	Si	S	P	Cr	Ni	Mo
0.31	0.54	0.53	-	-	1.26	-	0.52
V	Ti	Nb	B	Cu	Al	N	Co
0.27	-	-	-	-	-	-	1.06

Source: C. F. Jatcak, in "Hardenability Concepts with Applications to Steel", Eds. D. V. Doane and J. S. Kirkaldy, TMS-AIME, 1978, pp. 334-346.

Van ref: 90

Steel 100



Source: C. F. Jatcak, in "Hardenability Concepts with Applications to Steel", eds. D. V. Doane and J. S. Kirkaldy, TMS-AIME, 1978, pp. 334-346

Van ref: 93