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PROPOSED SPECIFICATION FOR AN HPS 100W Cu-Ni AGE-HARDENING ASTM A709 GRADE BRIDGE STEEL

by

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PROPOSED SPECIFICATION FOR AN HPS 100W Cu-Ni AGE-HARDENING ASTM A709 GRADE BRIDGE STEEL

ABSTRACT

On the basis of extensive laboratory studies, ATLSS recommended a Cu-Ni steel with significantly improved properties for 100W infrastructure applications, such as bridges. To confirm these results, a 165-ton full-scale heat of the recommended composition was produced. The products were evaluated for 100W applications by quenching and temper-aging.The investigation indicated that the production heat replicated quite faithfully the excellent strength, toughness, and weldability observed in the 100-pound laboratory heats. However, the yield strengths of the 2- and 2-1/2-inch-thick plates were only about 2-ksi above the 100-ksi minimum. Therefore, a laboratory heat was melted to determine if increase in the manganese content from 1.00 to 1.25 percent would produce the desired yield strength. The study led to the following results:

1.The hardenability and the yield and tensile strength after aging were increased sufficiently to ensure meeting a minimum yield strength of 100 ksi through 2-1/2-inch plates and 90 ksi over 2-1/2 to 4-inch plate.

2. On the basis of the present and previous ATLSS studies, the following specification for a 100W Cu-Ni age-hardening ASTM A 709 Grade is proposed:

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Al	N
0.050	0.95	0.015	0.003*	0.15	0.90	0.65	0.40	0.40	0.040	0.010	0.020	0.015
0.080	1.50	max	max	0.35	1.20	0.90	0.65	0.65	0.080	0.030	0.050	max

*Steels should be calcium-treated for sulfide shape control

INTRODUCTION

On the basis of extensive laboratory studies, ATLSS recommended a Cu-Ni steel with significantly improved properties for 100W infrastructure applications, such as bridges. To confirm these results, a 165-ton full-scale heat of the recommended composition was electric-furnace melted, bottom-poured into ingots, and converted to plates from ¼ to 2-½ inches thick and 10-inch-diameter seamless tubes. The products were evaluated for 100W applications by quenching and temper-aging.The investigation indicated that the production heat replicated quite faithfully the excellent strength, toughness, and weldability observed in the 100-pound laboratory heats. However, the yield strengths of the 2- and 2-1/2-inch-thick plates were only about 2-ksi above the 100-ksi minimum. Consequently, in production, rejections of these heavy-gage plates might be anticipated. Therefore, ATLSS recommended increasing the hardenability for heavy plates by increasing the manganese from 1.00 to 1.25 percent, and a 300-pound heat of this composition was melted and rolled by the U.S.Steel Technical Center. The results of this investigation and the previous studies (1 to 3) are combined herein to propose a specification for a 100W Cu-Ni age-hardening ASTM A709 Grade Bridge Steel.

.EXPERIMENTAL PROCEDURE

MELTING AND ROLLING

A 300-pound Laboratory heat was vacuum-melted at the U.S. Steel Technical Center and cast into a 5"x13"x16" ingot mold. The ingot was cut into two 8-inch long pieces. One piece was heated to 2150F (1175C) and rolled to a 2.1-inch-thick by 20-inch-long by 13-inch-wide plate. The second piece was heated to 2150F (1175C) and rolled to a 1.1-inch-thick by 20-inch-long by 13-inch-wide plate.The chemical compositions for the 165-ton production heat (R8660) and the Aim, Melt, and Plate check for the 300-pound Laboratory heat for the current study were as follows:

	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Al
Prod. Ladle	0.060	0.99	0.005	0.002	0.27	0.98	0.75	0.51	0.50	0.059	0.020	0.035
Lab Aim	0.060	1.25	0.010	0.003	0.25	1.00	0.75	0.50	0.50	0.060	0.020	0.025
Lab Melt	0.060	1.26	0.010	0.002	0.25	1.03	0.73	0.50	0.50	0.060	0.021	0.029
Lab Plate	0.058	1.27	0.010	0.004	0.25	0.99	0.71	0.51	0.50	0.060	0.022	0.031

JOMINY END-QUENCH-HARDENABILITY TESTING

From the 1-inch-thick plate, five longitudinal Jominy test specimens were machined, end-quenched, and tested in accordance with ASTM A255 (the austenitizing temperature was 1650F (900C). Two flats were ground on opposite sides of each specimen and a hardness traverse was conducted on each flat at appropriate intervals for two inches from the quenched end. One of each of the four Jominy specimens was aged at 950F, 1050F, 1150F, or 1250F (510C, 565C, 620C, or 675C), the flats were reground to remove the effects of prior testing, and the hardness traverses were repeated. Micrographs were obtained on the as-quenched specimen at 2/, 6/, 11/, 14/, 17/, and 32/16 inches from the quenched end.

HEAT TREATMENT AND MECHANICAL-PROPERTY TESTING

A 7-inch-long piece of the 1-inch-thick plate was austenitized at 1650F (900C) and quenched into mildly agitated water (H=1.5, cooling rate of 50F/sec (28C/sec)) to simulate spray quenching of a 1-inch-thick plate on a production facility. After cropping, the plate was cut into three 3.67-inch-wide by 5-inch-long pieces. Each of the three pieces was then aged for one hour at 1050F (565C), 1150F (620C), or 1250F (675C).

A second 7-inch-long piece of the 1-inch-thick plate was austenitized at 1650F (900C) and quenched into a circulated water bath containing 4.75% polyalkylene glycol (cooling rate of 9F/sec) to simulate spray quenching of a 4-inch-thick plate on a production facility. The plate was then cut and aged as described above.

A 7-inch-long piece of the 2-inch-thick plate was austenitized at 1650F (900C) and quenched into mildly agitated water (H=1.5, cooling rate of 20F/sec) to simulate spray quenching of a 2-inch-thick plate on a production facility. The plate was cropped on the top, bottom and both sides and cut into three 3-1/4-inch wide by 5-inch-long pieces, each of which was then aged at 1050F, 1150F, or 1250F (565C, 620C or 675C).

The 1- and 2-inch-thick aged subsections were machined into longitudinal 0.357-inch (9-mm) tension-test and standard Charpy V-notch-test specimens, which were centered at the quarterthickness location. . The tension tests were conducted in duplicate, and the Charpy tests were conducted over temperatures to obtain a transition curve.

RESULTS AND DISCUSSION

JOMINY END-QUENCH-HARDENABILITY TESTS

The Jominy test results for the Laboratory heat are plotted in Figure 1. As observed previously, the effect on hardness is a competition between temper softening and precipitation strengthening. The vertical lines identify the midthickness cooling rate for spray-quenched production plates of 1-, 2-, 3-, and 4-inch thicknesses, 50F, 20F, 12F, and 9F/second, respectively (28C, 11C, 6.7, and 5C/sec.), based on the cooling time from 800C to 500C (1472F to 932F).

As the aging temperature increased, temper softening predominates, particularly at the fast-cooled end where the hardness is highest. Thus maximum precipitation strengthening occurred at the lowest aging temperature, 950F (510C), and maximum temper softening occurred at 1250F (675C). However, even at 1250F (675C), some precipitation strengthening occurred at the lowest cooling rates of 20F/sec (corresponding to production quenching of 2-inch-thick plate) and lower. Thus the copper precipitation strengthening is of particular value for plates of increasing thickness, where it is most needed to meet strength specifications.

In general, the optimum combination of strength and toughness for 100W type copper precipitation-strengthened steels, particularly in heavy gages, has been observed at an aging temperature of about 1150F (620C). Therefore the Jominy curves at 1150F (620C) for the production heat and the Laboratory heat are compared in Figure 2, along with their respective as-quenched curves. For both conditions, the increase in the manganese content from 1.00 percent for the Production heat to 1.25 percent for the Laboratory heat was effective in increasing the hardness by about three points HRc, corresponding to a tensile strength increase of 5 ksi, and a similar increase in yield strength would be anticipated. This increase is important for 2-inch and thicker plates, with 1 percent manganese, which only marginally met the 100ksi yield-strength for 100W HPS. The micrographs for the six positions along the length of the Jominy specimen are illustrated in Figure 3. The microstructures vary from essentially complete martensite at 2/16 inch to primary ferrite plus granular bainite at 32/16 inches.

MECHANICAL-PROPERTY TESTS

The mechanical properties for 1-inch-thick water-quenched and polymer-quenched plates after aging at 1050F, 1150F, and 1250F (565C, 620C, and 675C) are listed in Table 1. Also listed are the mechanical properties for the 2-inch-thick aged plates and typical properties for the 1- and 2-inch-thick aged production-heat plates. The yield strength of the Laboratory heat 1-inch water-quenched plates are 4 to 5 ksi higher than the production plates as predicted from the Jominy curves. The results for the 1-inch polymer-quenched plates suggest that a yield strength close to 100 ksi might be obtained in 4-inch-thick production plates. However, considerable retreatment might be required.

The Charpy V-notch data are also listed in Table 1 for absorbed energy at various temperatures and for transition temperatures based on absorbed energy, lateral expansion, and fracture appearance. The transition-temperature absorbed-energy curves for the 1- and 2-inch plates from the lab heat and the production heat are illustrated in Figure 4, and show that the transition from ductile to brittle behavior occurred at a slightly lower temperature for production plates than for the lab plates. This difference is consistent with the increased strength contributed by the higher manganese content. For all plates, the transition temperatures occurred at very low temperatures and the shelf energies exceeded 100 ft.lb. Also the 1-inch polymer-quenched plate, which was cooled at 9F/second to simulate production quenching of a 4-inch plate, exhibited toughness values almost as good as those for the 1-inch water-quenched plate. In general, the fracture toughness of all the plates far exceeded the specification of 35 ft.lb at –30F (41J at –34C) for 100W fracture-critical members in Zone 3. Thus some of the limitations imposed on Zone 3 for 100W fracture-critical members might be relaxed for this Cu-Ni steel.

WELDABILITY

Implant tests results on production-heat plates reported in Reference 3 indicated that the steel should be weldable without preheat. Implant tests were not run on the lab heat because results on similar compositions are available in Reference 2 that indicate that preheat should not be necessary. However, because the implant test is a small-scale test, larger-scale tests are currently underway to confirm the results of the implant tests.

PROPOSED SPECIFICATION

On the basis of the information contained in the references and the present study, the following composition is proposed for a Cu-Ni 100WF Grade A709 Bridge steel.

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Al	N
0.050	0.95	0.015	0.003*	0.15	0.90	0.65	0.40	0.40	0.040	0.010	0.020	0.015
0.080	1.50	max	max	0.35	1.20	0.90	0.65	0.65	0.080	0.030	0.050	max

*Steels should be calcium-treated for sulfide shape control

The above composition range is proposed for plate gauges up to 2-1/2 inches. For over 2-1/2 to 4 inches inclusive, a reduction in the minimum yield strength from 100 ksi to 90 ksi is proposed. Producers would be expected to adjust the composition within the proposed ranges according to plate gauges.

CONCLUSIONS

An increase in the manganese content from 1.00 percent, which was evaluated in the 165-ton HPS 100W Cu-Ni production heat, to 1.25 percent in a laboratory heat led to following results:

1. The hardenability and the yield and tensile strength after aging were increased sufficiently to ensure a minimum yield strength of 100 ksi through 2-1/2-inch plates.

2. On the basis of the present and previous ATLSS studies, a specification for a 100W Cu-Ni age-hardening ASTM A 709 Grade is proposed.

REFERENCES

1. Dawson, H.M., Gross, J.H., and Stout, R.D., “Copper-Nickel High Performance 70W/100W Bridge Steels - Part 1”, ATLSS Report No. 97-10, August 1997.

2. Gross, J.H., Stout, R.D., and Dawson, H.M., “Copper-Nickel High Performance 70W/100W Bridge Steels - Part II”, ATLSS Report No. 98-02, May 1998.

3. Gross, J.H. and Stout, R.D., "Evaluation of a Production Heat of an Improved Cu-Ni 70W/100W Steel", ATLSS Report No. 01-10, June 2001

ACKNOWLEDGEMENTS

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Processing Condition Temperature, °F	Codes	Tensile Properties Y.S. ksi	T.S ksi	EL. %	R.A %	Y.S./T.S.	Hard. HRc	Charpy V-Notch Transition Temp., °F 20 ft-lb	35 ft-lb	60 ft-lb	15 mils	50% FAT	Charpy V-Notch Energy ft-lb 70°F	0°F	-40°F	-80°F	-120°F
Laboratory Heat																	
1-inch-thick plate-Water Quenched Quarter-Thickness																	
Aust. 1650F+WQ+Aged 1050F	BAB	119	129	31	74	0.92	29.2	-125	-120	-110	-125	5		115	100	90	40
Aust. 1650F+WQ+Aged 1150F	BAD	118	125	24	76	0.94	27.6	<-120	<-120	-125	<-120	-75		165	130	115	70
Aust. 1650F+WQ+Aged 1250F	BAF	107	112	25	76	0.96	22.3	<-120	<-120	<120	<120	-120		185	175	150	150
1-inch-thick plate-Polymer Quenched Quarter-Thickness																	
Aust. 1650F+PQ+Aged 1050F	BBB	101	123	24	72	0.82	23.8	-115	-110	-90	-115	>0		115	85	85	15
Aust. 1650F+PQ+Aged 1150F	BBD	103	118	26	76	0.87	23.7	<-120	<-120	-115	<-120	-45		195	115	70	60
Aust. 1650F+PQ+Aged 1250F	BBF	95	106	29	80	0.90	20.0	<-120	<-120	<-120	<-120	-60		180	150	135	100
2-inch-thick plate-Water Quenched Quarter-Thickness																	
Aust. 1650F+WQ+Aged 1050F	BABQ	100	118	24	75	0.83	24.5	-85	-75	-65	-80	70		118	88	30	------
Aust. 1650F+WQ+Aged 1150F	BADQ	111	121	25	74	0.92	24.0	-105	-100	-95	-105	40		120	110	100	15
Aust. 1650F+WQ+Aged 1250F	BAFQ	91	102	28	78	0.89	18.0	-115	-105	-100	-110	-30		200	145	120	10
Production Heat																	
1-inch-thick-Mill Quenched-1650F Quarter-Thickness																	
Lab Aged 1050F		114	126	27	74	0.90	26.5	<-120	<-120	-120	<-120	-45		135	124	114	63
Lab Aged 1150F		114	122	25	78	0.93	25.5	<-120	<-120	<-120	<-120	-60		158	142	132	86
Lab Aged 1250F		103	109	27	78	0.94	20.5	<-120	<-120	<-120	<-120	-100		196	194	164	135
2-inch-thick-Mill Quenched-1650F Quarter-Thickness																	
Lab Aged 1050F		100	116	26	72	0.87	23.0	-120	-115	-110	-115	0		130	112	92	15
Lab Aged 1150F		105	115	27	75	0.91	24.2	<-120	<-120	<-120	<-120	-50		170	132	134	95
Lab Aged 1250F		96	103	27	78	0.93	19.0	<-120	<-120	<-120	<-120	-60		208	150	158	122

Table I - Mechanical Properties of Laboratory Heat Compared with Production Heat

Figure 1 - Averaged Jominy End-Quenched Hardenability Results for Lab Heat BB

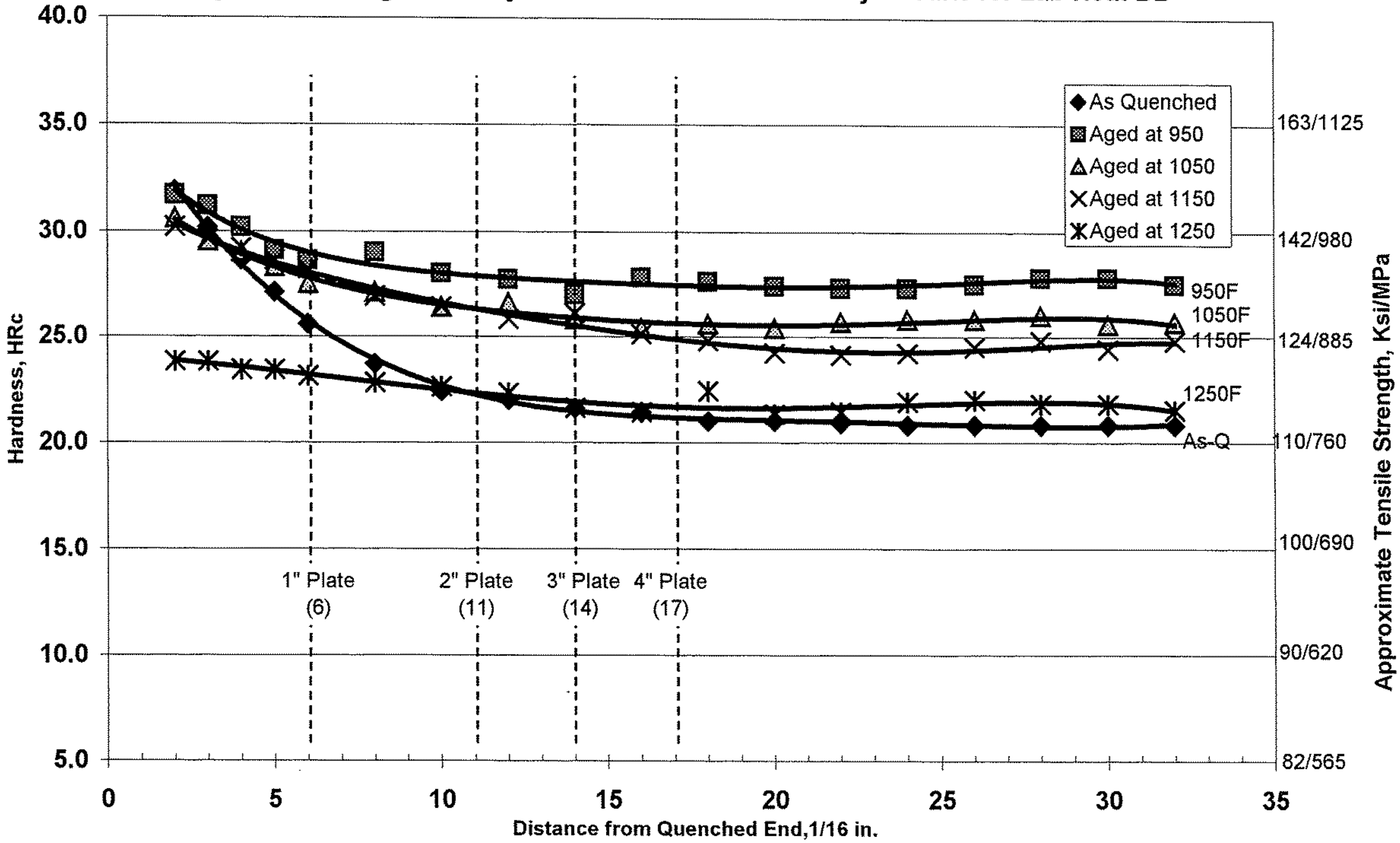
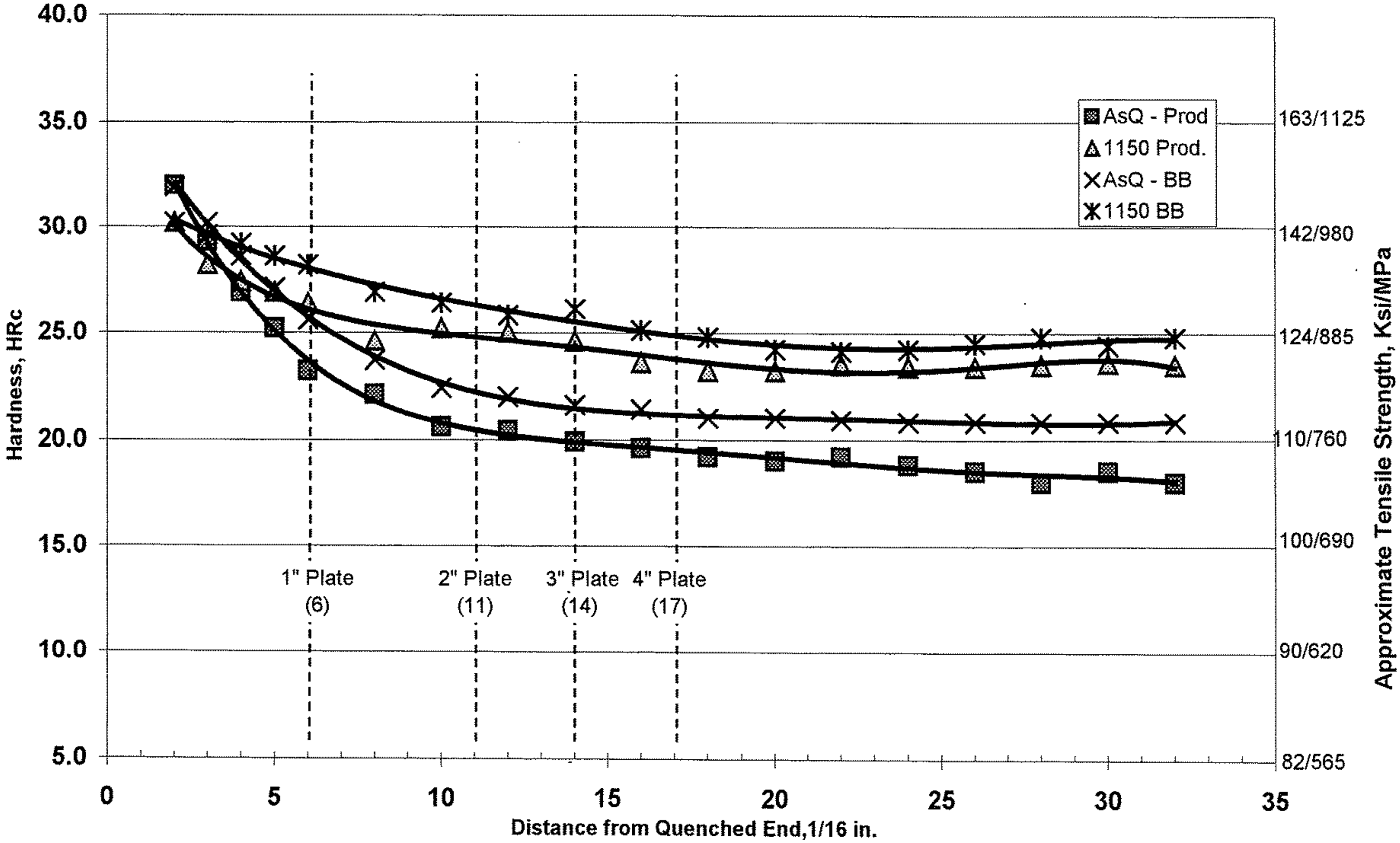
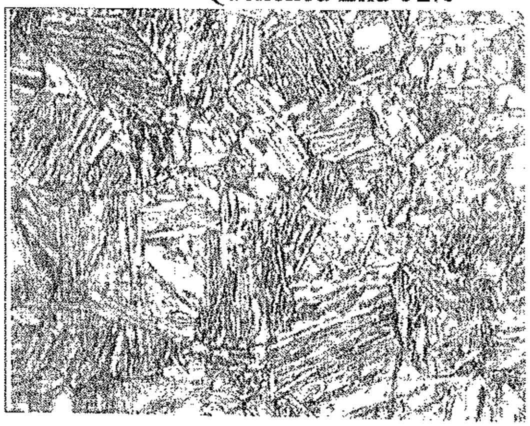


Figure 2 - Comparison of Jominy Curves for Production Heat and Lab Heat BB

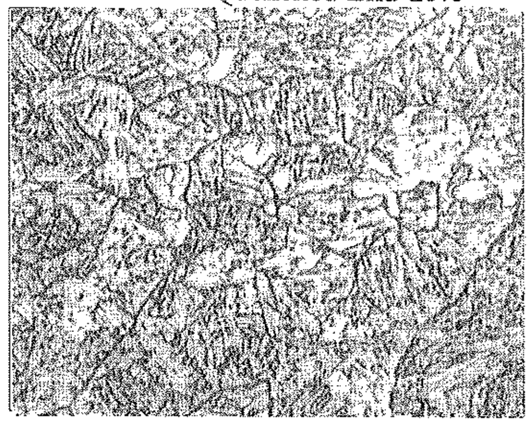


C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Al
0.058	1.27	0.010	0.004	0.25	0.99	0.71	0.51	0.50	0.060	0.022	0.031

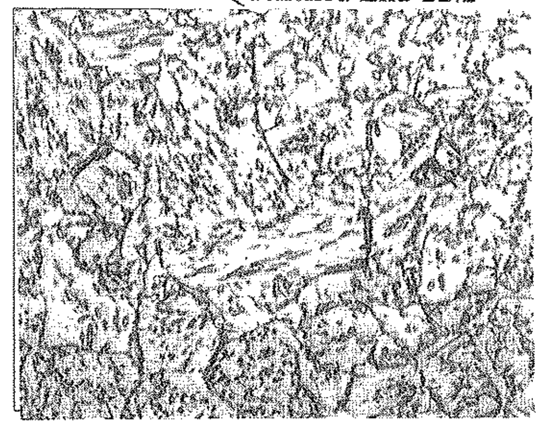
2/16" From Quenched End-32.0*



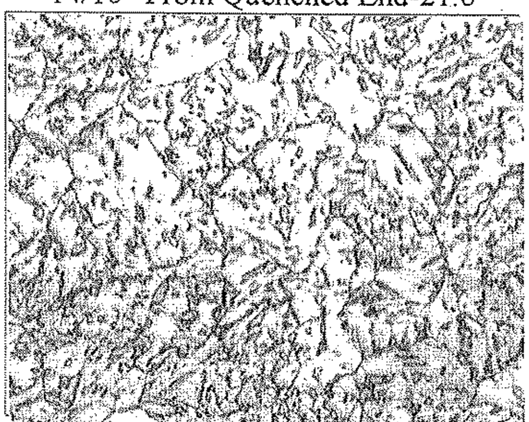
6/16" From Quenched End-25.6*



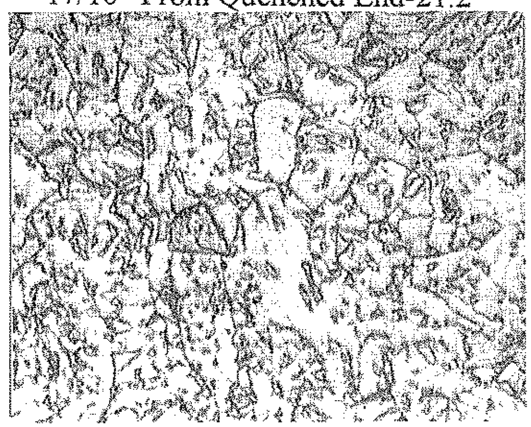
11/16" From Quenched End-22.2*



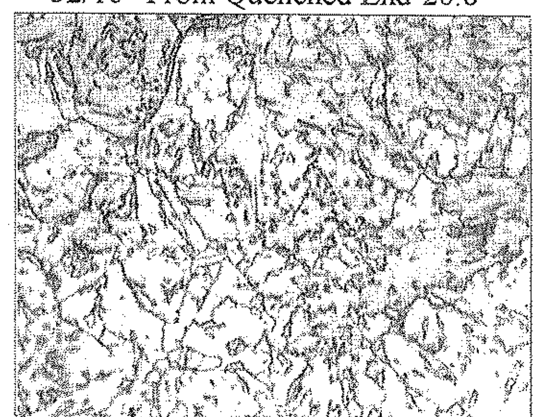
14/16" From Quenched End-21.6*



17/16" From Quenched End-21.2*



32/16" From Quenched End-20.8*



*Rockwell "C" Hardness

X850 Nital - Picral

Figure 3 – Jominy End-Quenched-Hardenability Microstructures – As quenched – Laboratory Heat BB

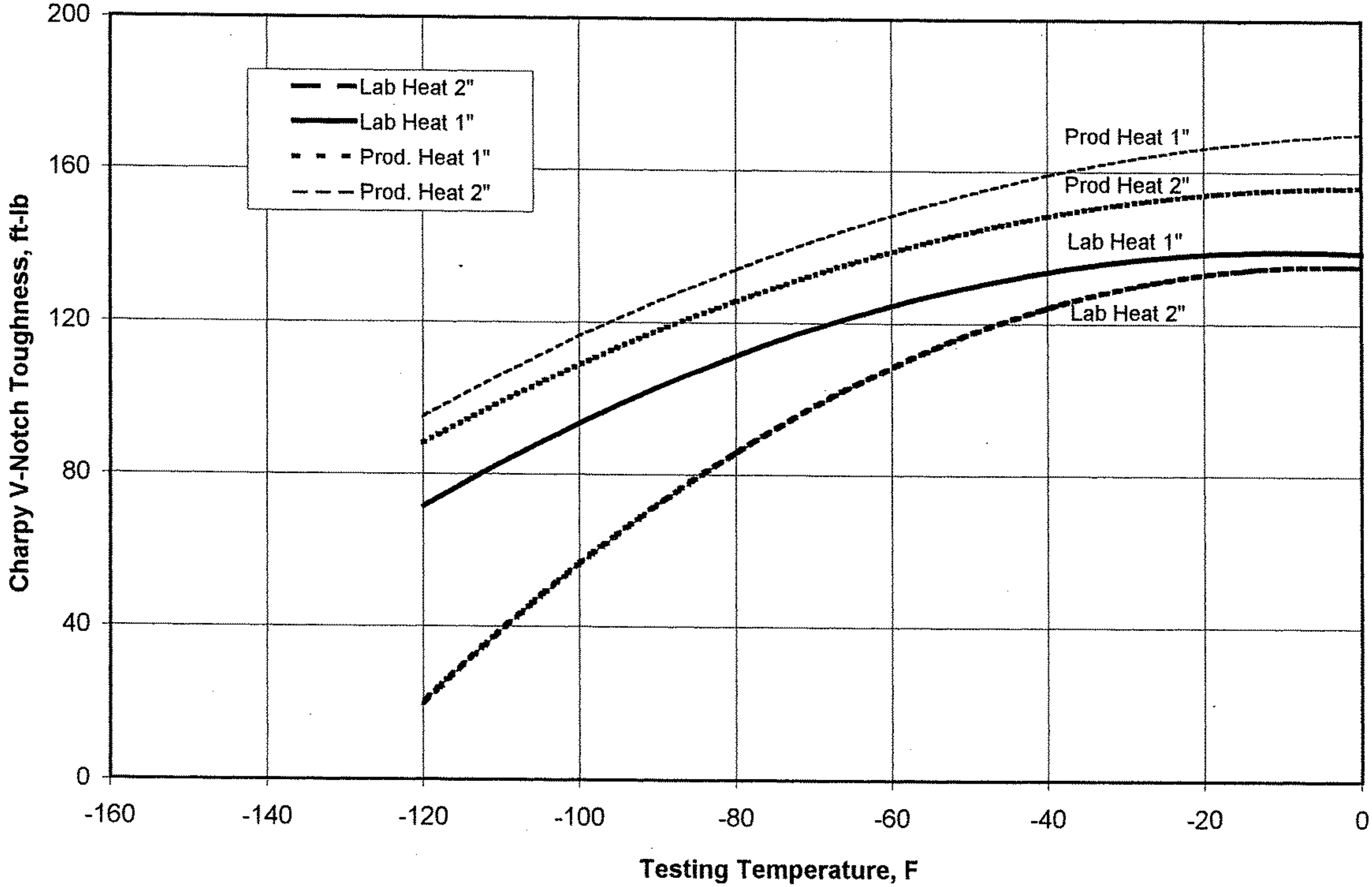


Figure 4 - Energy Transition Curves for Lab Heat and Production Heat