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by

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EVALUATION OF A PROPOSED COMPOSITION OF Cu-Ni HPS-120W STEEL

ABSTRACT

A previous ATLSS study reported the composition of a Cu-Ni steel that was considered a good candidate for an HPS-120W steel. Therefore, an 11,000-pound, 9-inch thick continuously cast slab was purchased from a 165-ton electric-furnace heat of Cu-Ni steel melted by the Lukens Division of Mittal Steel. The slab was rolled to a 1-inch-thick plate, 72 by 560 inches, and heat-treated by Lukens. The composition of the steel was as follows:

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Al	N
0.06	1.04	0.015	0.001	0.29	1.14	2.44	0.65	0.49	0.001	0.03	0.04	0.009

After rolling and heat treatment, a 420-inch-long plate was shipped to ATLSS for large-scale-prototype fabricated-girder tests for strength, ductility, fatigue, and fracture, and a 144-inch-long piece for mechanical-property and weldability tests.

The mechanical properties of the 1-inch-thick plate met the the desired average tensile properties: yield strength (125ksi), tensile strength (130ksi), elongation (24%), and reduction of area (70%). The fracture toughness based on the Charpy V-notch test averaged over 100 foot pounds at -150F. The weldability as measured by the slow-notch-bend test containing 120ksi yield-strength weld beads demonstrated that the transverse machined Charpy V-notch did not extend when the specimen was bent one inch at -60F (-50C). At temperatures down to -130F (-90C), cracks popped-in at deflections around 0.50 inch but were arrested by the base plate, and the arrested crack did not result in full fracture until the specimen was bent farther.

The results indicate that 1-inch-thick plate of the composition of the proposed Cu-Ni steel should meet the properties desired in various infrastructure applications. Simulated 3-inch-thick plate also met the desired properties but the temper-aging temperature had to be reduced to 1000F (595C), lower than the minimum 1100F (595C) that is commonly required for post-weld treatment. Therefore, in plates thicker than 1 inch, an increase in manganese to 1.50% to increase hardenability along with an increase in vanadium to 0.06% to increase resistance to softening during tempering is recommended so that temper-aging can be performed at or above 1100F.

A commercial heat with the increased manganese/vanadium composition is recommended to evaluate the properties of heavy-gage plates.

INTRODUCTION

A previous ATLSS study* reported the composition of a Cu-Ni steel that was considered a good candidate for an HPS-120W steel. Therefore, an 11,000-pound, 9-inch thick continuously cast slab was purchased from a 165-ton electric-furnace heat of Cu-Ni steel melted by the Lukens Division of Mittal Steel. The slab was rolled to a 1-inch-thick plate, 72 by 560 inches, and heat-treated by Lukens. The composition of the steel was as follows:

	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Al	N
Ladle	0.06	1.04	0.015	0.001	0.29	1.14	2.44	0.65	0.49	0.001	0.03	0.04	0.009
Check	0.06	1.02	0.004	0.003	0.28	1.15	2.46	0.66	0.47	0.005	0.03	0.04	0.008

Small pieces of as-quenched plate were temper-aged (hereafter referred to as aged) by ATLSS at 1100, 1150, or 1200F (595, 620, or 650C) . The aged pieces were machined into tensile and Charpy V-notch tests and the results were used to select the temperature for aging the as-quenched plate at Lukens, which was then shipped to ATLSS. A 420-inch-long plate was provided for large-scale-prototype fabricated-girder tests for strength, ductility, fatigue, and fracture tests, and a 144-inch-long piece for mechanical-property and weldability tests.

EXPERIMENTAL PROCEDURE

Jominy End-Quench-Hardenability Tests

Jominy end-quench-hardenability test specimens were machined from the 1-inch plate and tested in accordance with ASTM A255 (austenitized at 1650F, 972C). After quenching, specimens were aged at 1100F, 1150F, or 1200F (595C, 620C, 650C). The hardness-testing flats were polished and etched along the full length and photographed at various distances from the quenched end corresponding to the cooling rate at the midthickness of 1/2-, 1-, 1-1/2-, 2-, and 3-inch-thick commercially quenched plate.

Mechanical-Property Tests

Production-heat-treated plate- The mechanical-property test specimens were machined so that they were centered at the quarter-thickness location of the 1-inch plate. The tension specimens were tested to obtain the 0.2% offset yield strength, tensile strength, elongation, and reduction of area. The Charpy specimens were tested over a range of temperatures to obtain the energy absorbed at various temperatures so that transition-temperature curves could be plotted to select various standard energy values.

Simulated 3-inch-thick plate- An 8-by12-inch plate was austenitized at 1650F (900C) and quenched in agitated water containing 4.75% polyalkylene glycol, which produced a cooling rate of 9F/sec. (5C/sec.) at the center of a 1-inch-thick plate, which corresponds to the cooling rate at the center of a commercially spray-quenched (H=1.5) 3-inch-thick plate. The mechanical-property tests used for the aged commercial plate were repeated on the simulated 3-inch-thick plate.

* Stout,R.D. and Gross, J.H.,"Development of Compositions of Cu-Ni High-Performance Steels with Yield Strengths of 100- to 130-ksi and Excellent Toughness", ATLSS Report No. 05-11, June 2

Weldability Tests

Slow-notch-bend-tests were run on 3-inch-wide by 14-inch-inch-long samples after depositing two overlapping SAW 5-inch weld beads centered on the length of each test specimen. The welding conditions were 475 amps, 30 volts at 8 inches/min. a heat input of approximately 43,000 Joules/inch. The specimen was notched transversely at the midlength using a standard Charpy V-notch to a depth of 0.050 inch in the base plate.

RESULTS AND DISCUSSION

Jominy-Test Results

The results of the Jominy tests as-quenched, and as-quenched and aged at various temperatures are depicted in Figure 1. The curves show that aging at 1000F (535C) resulted in slight softening for 4 sixteenths at the fast-cooled end but thereafter, strengthening due to aging greatly exceeded softening. At 1100F (575C) net softening occurred up to 10 sixteenths from the quenched end. Beyond that distance, the strengthening due to aging exceeded the temper softening by about 5ksi in tensile strength. After aging at 1150F (620C), temper softening exceeded aged-strengthening up to about 20 sixteenths; beyond which the as-quenched and aged tensile strength were essentially the same. Although not shown, aging at 1200F (650C) resulted in significant softening at all distances from the quenched end. These data are useful in predicting the probable strength in plates of various thicknesses after various aging treatments.

The microconstituents that resulted along the length of the various Jominy specimens are illustrated in Figure 2. The micrographs of the steel exhibited lath-like martensitic microstructures at the quenched end when cooled at 195F/sec. (108C/sec.). At greater distances from the quenched end, the microconstituents were various combinations of ferrite, martensite, and MA (martensite-austenite). These micrographs illustrate the gamut of microstructures to be encountered when the Cu-Ni steels are production-quenched and temper-aged in plates ¼ to 3-inches thick.

Mechanical-Property Tests

The results of the mechanical-property tests conducted at the Lukens Steel Division of Mittal and by ATLSS are listed in Table I. The hardness of the commercially as-quenched plate and the polymer-quenched plate averaged 30 Rc which equates to a tensile strength of 140 ksi. Thus at the typical yield-tensile ratio of 90 percent after aging, a minimum yield strength of 120 ksi is feasible.

When the mill-quenched plate was lab aged at 1100F (595C), the yield strength of 123 ksi met the required minimum. However, after aging at 1150F (620C), the yield of 114 ksi fell well below the required minimum, and when the plates were mill-quenched and mill-aged at 1140F (615C), the yield strength of 121 ksi was too close to the minimum to be acceptable. When the mill treatment was repeated but at an aging temperature of 1100F (595C), the minimum was readily met at 128 ksi. These results illustrate the sensitivity to aging and indicate the need for careful control to avoid repeated heat treatment. Similarly, the polymer-quenched plate, simulating 3-inch-thick plate, required a reduction in aging temperature to 1000F (540C) to meet safely the minimum yield of 120 ksi.

These data are consistent with the strength values suggested by the Jominy curves for aging at 1000 or 1100F (540 or 595C).

In contrast to the yield strength, the Charpy V-notch toughness was excellent for all heat treatments and exceeded 100 foot pounds at temperatures down to -150F (-100C), except for the polymer-quenched plate aged at 1000F (540C). Even the 50% fibrous fracture temperature was close to or below -100F (-75C).

Collectively, these data indicate that the proposed chemical composition is suitable for an HPS120W steel, but the required aging temperatures are somewhat lower than generally specified in Standards. This problem could be remedied by increasing the manganese to 1.50 percent to enhance hardenability and by increasing the vanadium to 0.06 percent to resist softening during tempering. Therefore, the following revised composition is proposed for an HPS-120W steel for plates through three inches thick.

	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Al	N
Aim*	0.06	1.50	0.010	0.003	0.30	1.15	2.50	0.50	0.50	0.060	0.020	0.04	0.020

*Ranges and maximum values that fit commercial production will be proposed to ASTM.

This composition is essentially the same as that for Steel H6 described in References 8 and 9, in which it was reported that this composition should be suitable for an HPS-120W steel in thicknesses through three inches.

Weldability-Tests

The results of the slow-notch-bend tests were as follows:

Test	Test Temp (F)	Pop-In		Max Load	Deflection
		kips	inches	kips	inches
R1	-60	-----	-----	46.7	1.00+
R2	-100	47.0	0.42,0.46	47.5	0.91
R3	-130	46.8	0.47	49.5	0.63

Note that at -60F(-50C), the most severe service temperature in the USA, the Charpy-type notch with a root radius of 0.01 inch, did not propagate when the specimen was bent to the imposed maximum of one inch. At -100F(-70C), a crack popped-in at the root of the notch when the specimen was bent 0.44 inch but the crack was arrested by the base plate and fracture did not occur until the specimen was bent 0.91 inch, close to the maximum bend imposed. Essentially, the same results were observed at -130F(-90C) as at -100F. These results indicate that this steel provides an unusually tough weldment at a minimum yield strength of 120 ksi.

CONCLUSIONS

The results indicate that 1-inch-thick plate of the composition of the proposed Cu-Ni steel should meet the properties desired in various infrastructure applications. Simulated 3-inch-thick plate also met the desired properties but the temper-aging temperature had to be reduced to 1000F (595C), lower than the minimum 1100F (595C) that is commonly required for post-weld treatment. Therefore, in plates thicker than 1 inch, an increase in manganese to 1.50% to increase hardenability along with an increase in vanadium to 0.06% to increase resistance to softening during tempering is recommended so that temper-aging can be performed at or above 1100F.

A commercial heat with the increased manganese/vanadium composition is recommended to evaluate the properties of heavy-gage plates.

REFERENCES

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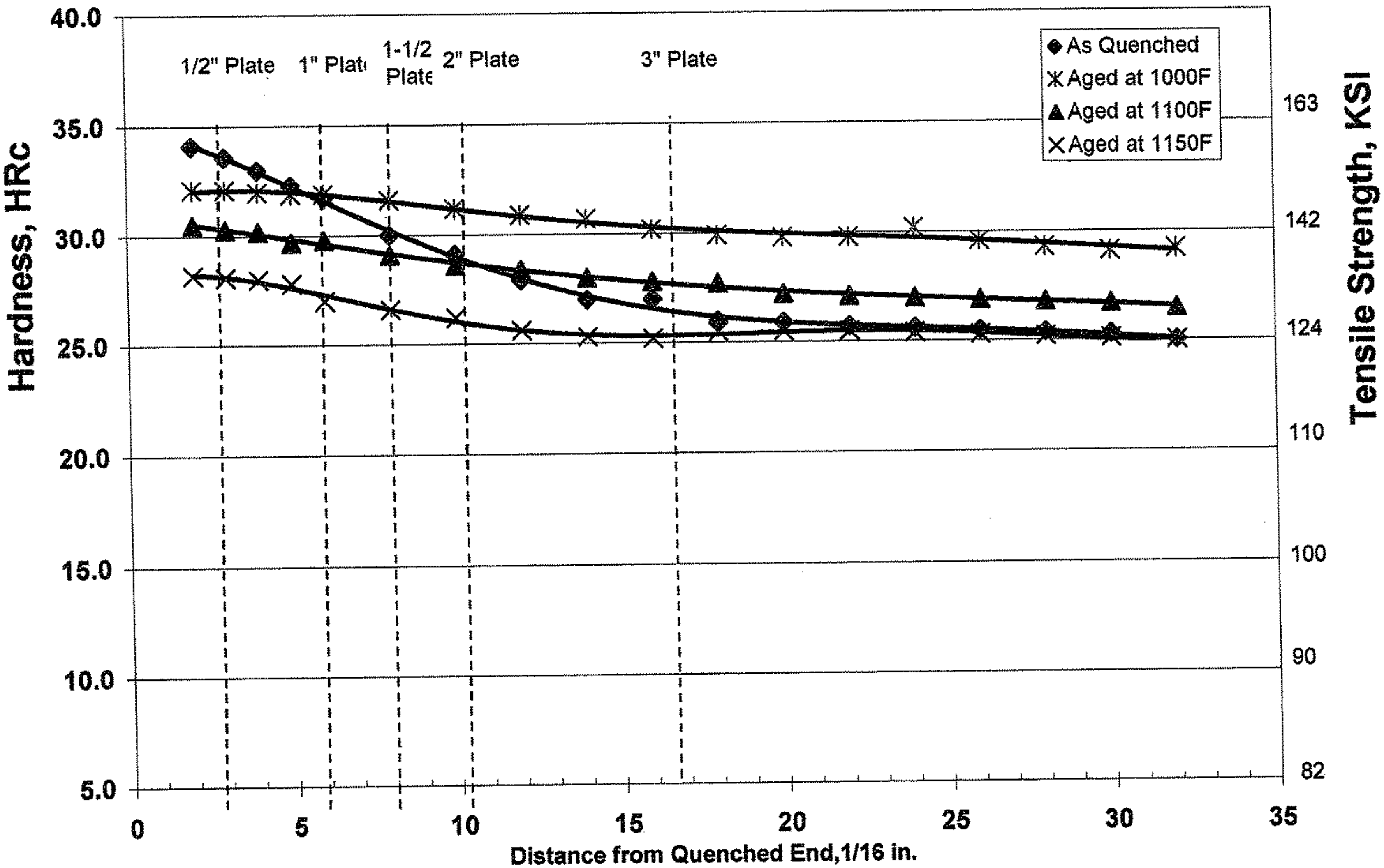
Table I - Mechanical Properties of Steel R After Various Heat Treatments

Heat Treatment	Yield Str - ksi	Tensile Str - ksi	Charpy V-Notch Toughnness, ft-lb @ -40F	-80F	-120F	-150F	50%Fibr. Fract, F
Mill Quenched & Lab Aged							
1100F	123	130	150	140	135	105	-150
1150F	114	120	160	160	155	150	<-150
Polymer Quenched & Lab Aged							
1000F	126	137	110	95	75	55	-80
1100F	116	127	165	150	130	105	-110
1150F	106	117	190	180	175	150	-150
1200F	102	113	200	175	165	160	<-150

Mill Quenched & Mill Aged	Yield Str - ksi	Tensile Str - ksi	Charpy Toughness @ -30F	-60F
1140F	121	125	150	145
1100F	128	134	160	162

Figure 1 - Jominy Hardenability of Steel R



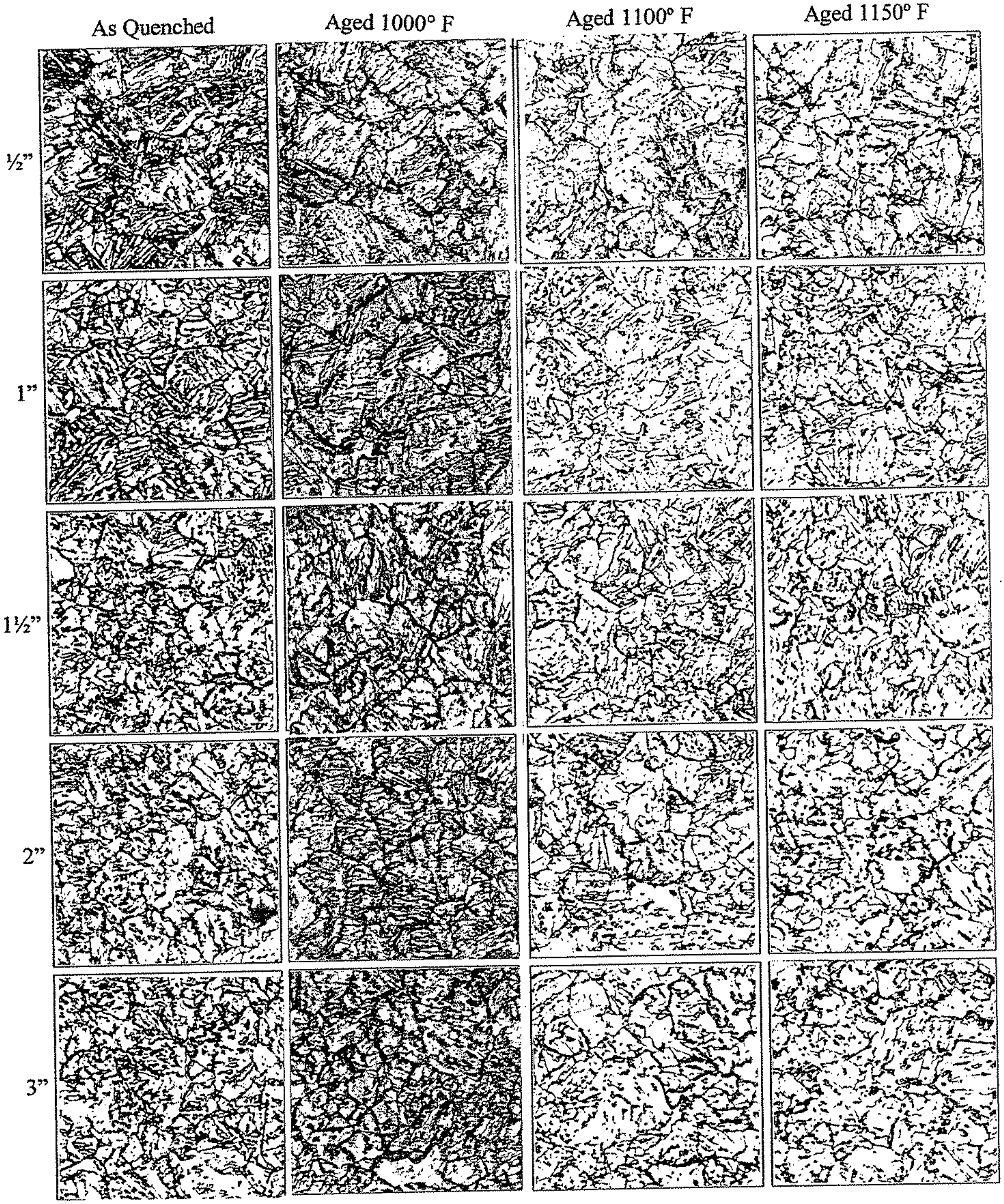


Figure 2 – Microstructures Representative of Commercial Heat Treatment of Steel R