

Development of Carpenter Micro-Melt 440XH Alloy (CarTech CTS[®] XHP)



RESEARCH AND DEVELOPMENT

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What is Carpenter 440XH Alloy?

- An Air Hardening, High Carbon, High Chromium Corrosion Resistant Alloy
- 440XH can be described as either:
 1. A High Hardness 440C Stainless Steel, or
 2. A Corrosion Resistant D2 Tool Steel

Nominal Composition of 440XH

C	Cr	Mn	Si	Ni	Mo	V
1.6	16.0	0.5	0.4	0.35	0.8	0.45

Development of Wrought 440XH

*U.S. Patent No.
5,370,750*

Customer Needed:

Corrosion Resistance of 440C

+

As-Quenched Hardness of 60 HRC minimum

+

Air Hardening

Carpenter's R&D Objective

To develop an alloy with the Corrosion Resistance of 440C and the As-Air Cooled Hardness of D2 (60 HRC Minimum) over a broad range of Hardening Temperatures.

Three Approaches

1. Improve the Corrosion Resistance of D2 without degrading As-Quenched Hardness (3 Heats + D2 Control)
2. Improve the As-Quenched Hardness of 440C without degrading Corrosion Resistance (3 Heats+ 440C Control)
3. Develop a New Alloy from first principles (2 Heats)

Procedure

1. VIM melt Ten (10) 34-lb. Heats (Split Cast into 17-lb. ingots)

2. Forge to 1.25" X 1.25" and 3.5" X .625" Bars

3. Testing

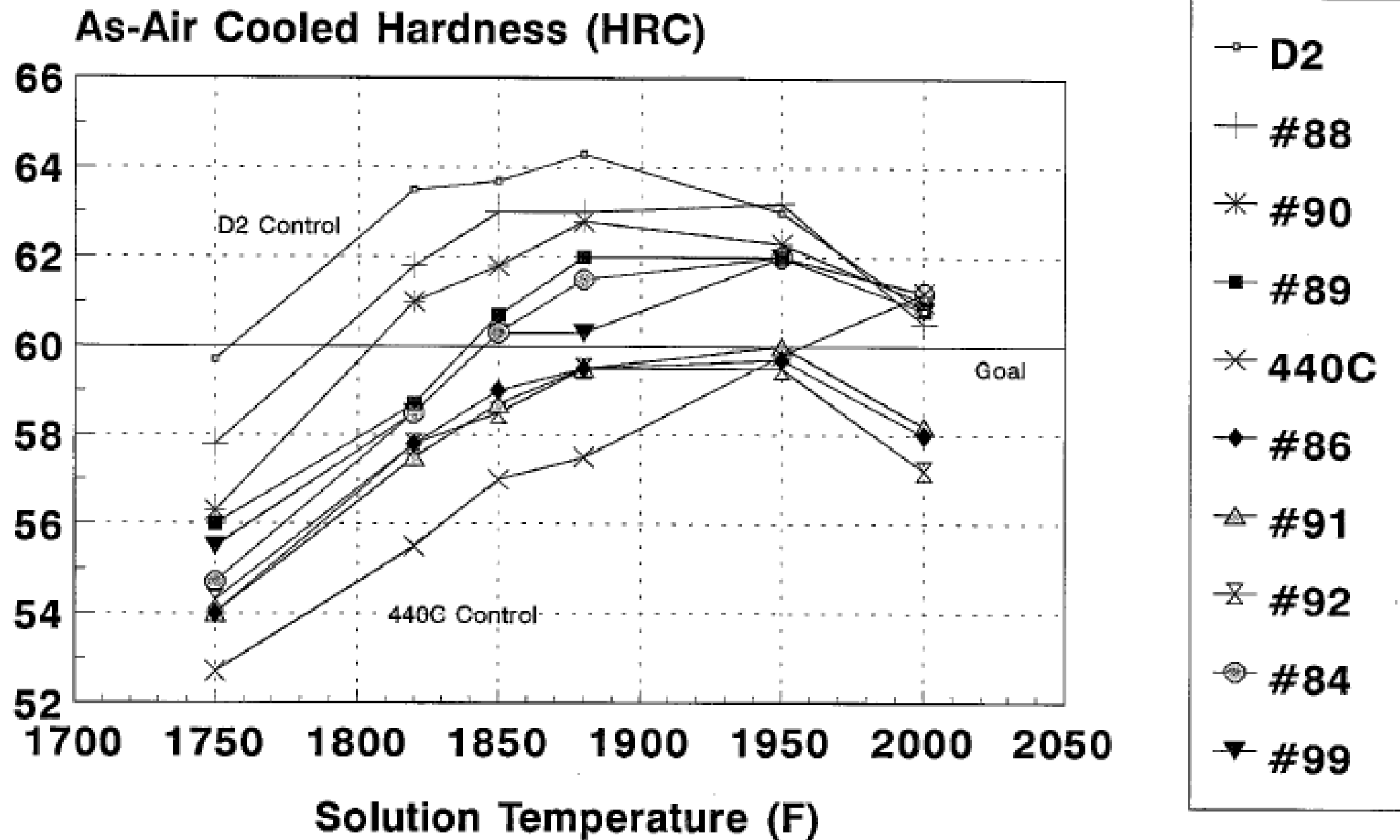
A. Testing for Mill Processability

- As-Cast Microstructure
- Hot Upset Testing (3:1 & 5:1 Reductions)

B. Property Testing

- Corrosion Cone Testing (95% Humidity/95°F)
- As-Quenched Hardness
- Tempered Hardness

As-Air Cooled Hardness vs. Solution Temperature



A92004

Humidity Testing of Non-Passivated Cones

Order of Heats (by Heat No.) at Each Test Interval

<u>Rank No.</u>	<u>1 h</u>	<u>8 h</u>	<u>24 h</u>	<u>72 h</u>	<u>200 h</u>
1 (Best)	91	440C	89	440C	91
2	440C	89	440C	89	440C
3	89	91	91	91	89
4	86	90	88	88	86
5	D2	86	86	86	88
6	90	88	90	D2	D2
7	84	D2	D2	90	90
8	88	92	92	92	92
9	92	84	99	84	99
10 (Worst)	99	99	84	99	84

(440C = HEAT 85; D2 = HEAT 87)

Conclusion

Heat #89 has the corrosion resistance of 440C combined with a 60 HRC minimum as-air cooled hardness over a wide solution temperature range of 1850 to 2000° F.

Comparison of 440XH, 440C and D2 Compositions

<u>Element</u>	<u>440XH</u>	<u>AISI 440C</u>	<u>AISI 02</u>
C	1.60	.95/1.2	1.40/1.60
Mn	.50	1.0 MAX	.60 MAX
Si	.35	1.0 MAX	.60 MAX
P	.020 MAX.	.04 MAX	-----
S	.005 MAX.	.03 MAX	-----
Cr	16.0	16.0/18.0	11.0/13.0
Ni	.35	-----	.30 MAX
Mo	.80	.75 MAX	.70/1.20
V	.45	-----	1.10 MAX
N	.05	-----	-----
Co	-----	-----	1.0 MAX

Typical Properties of Wrought 440XH

Typical Mechanical Properties of Annealed 440XH

<u>Y.S.</u> <u>(ksi)</u>	<u>U.T.S.</u> <u>(ksi)</u>	<u>Elong.</u> <u>(%)</u>	<u>R.A.</u> <u>(%)</u>	<u>Hardness</u> <u>BHN</u>
68.3	125.3	10.2	16.0	230/255

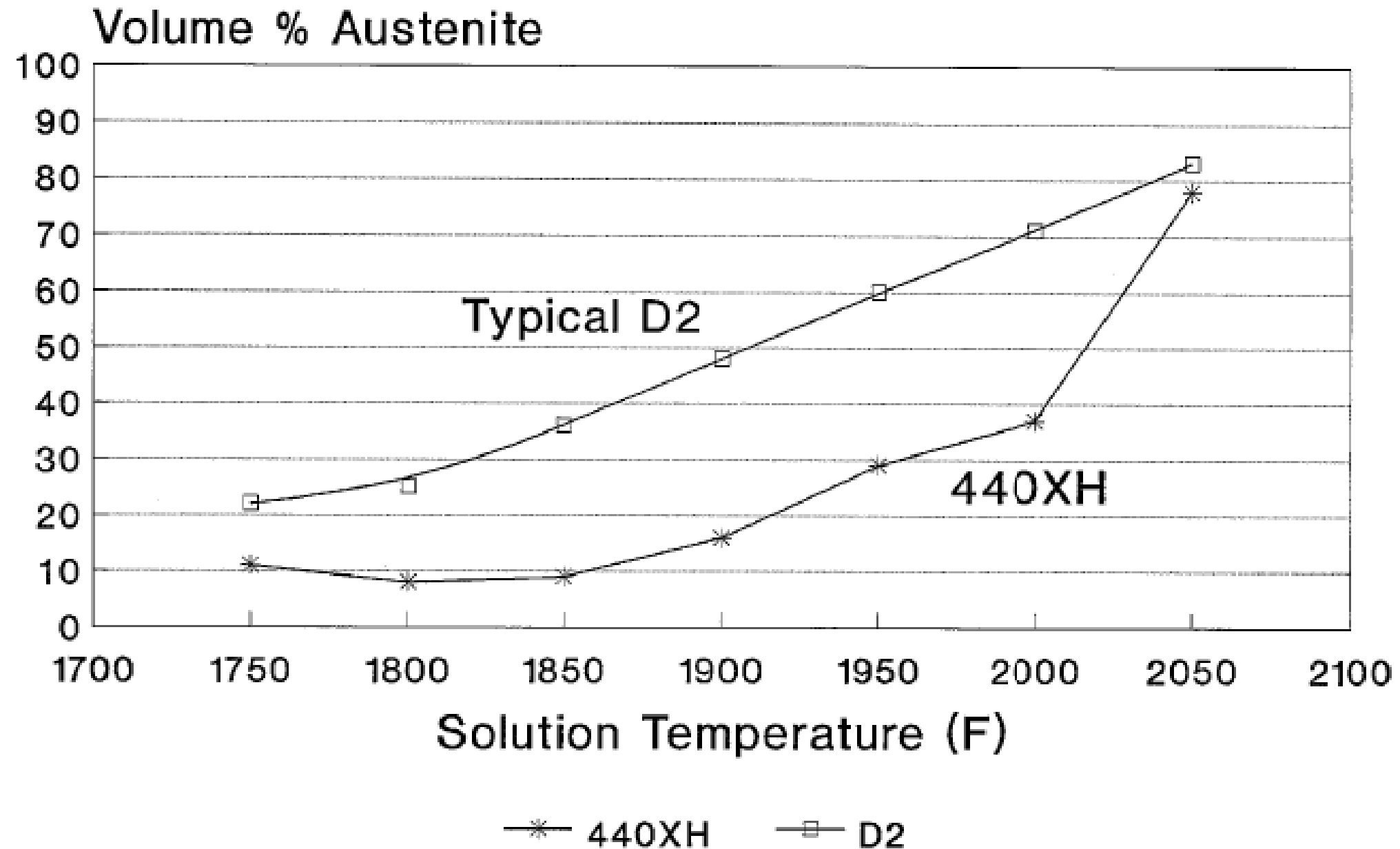
ASTM G65 Dry Sand/Rubber Wheel Abrasion Test Results

<u>Material</u>	<u>Hardness, HRC</u>	<u>Average ASTM</u> <u>Volume Loss (mm³)</u>
440XH	62.5	35.1
440C	58.5	66.9

Machinability

440XH machines the same as 440C

Volume% Austenite in 440XH and D2 Air Cooled from Solution Temperature

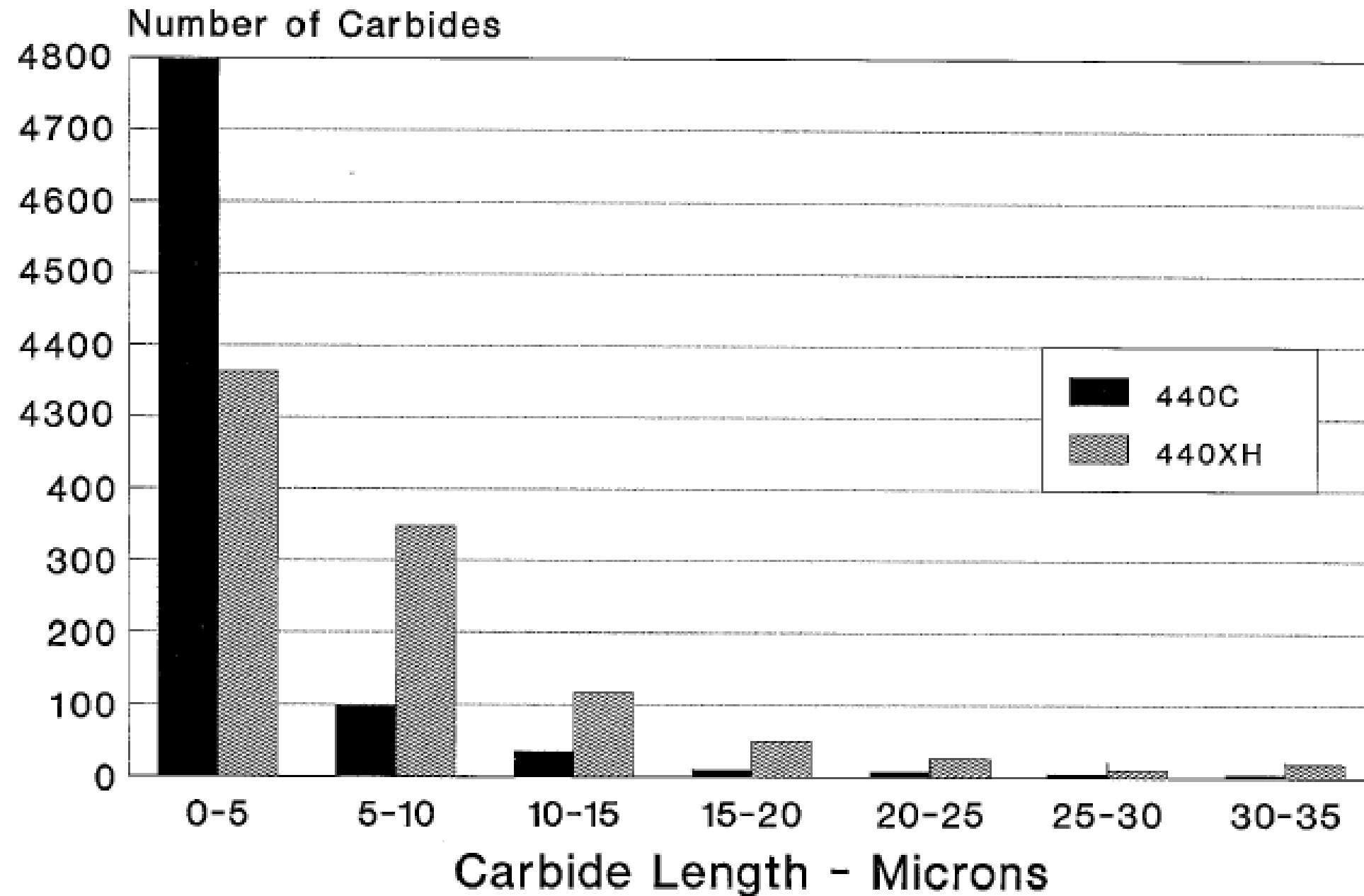


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EX00103 - 25 mins. @ Solution Temperature, Air Cooled
D2 Data from Tool Steels, 4th ed., Roberts & Cary

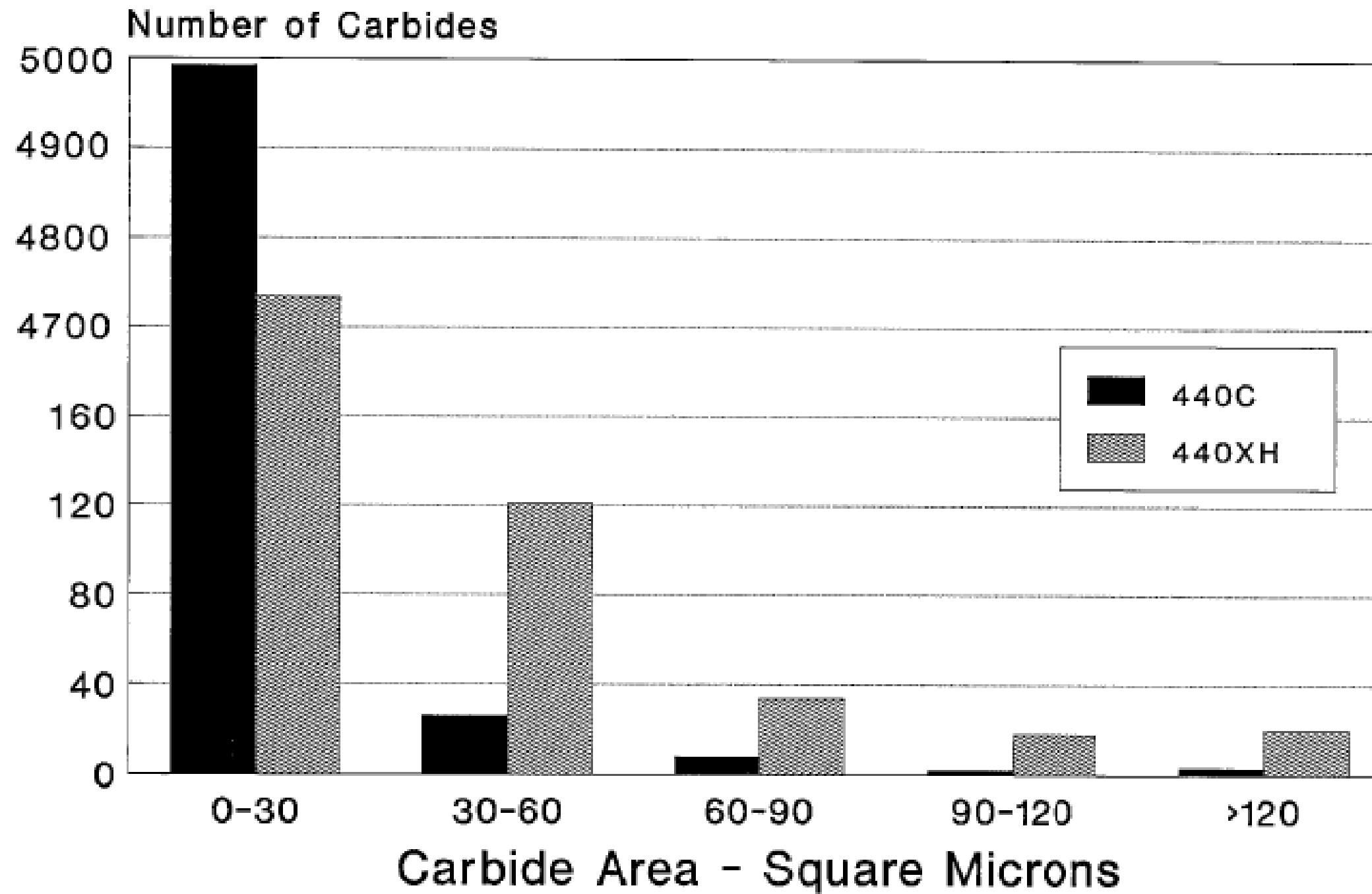
Microstructure Comparison

Carbide Length Distribution Wrought 440C vs. Wrought 440XH



Carbide Area Distribution

Wrought 440C vs. Wrought 440XH



Development of MicroMelt 440XH

P/M Processing of 440XH would:

- Provide Higher Hardness
- Refine Microstructure
- Reduce Grain Size
- Increase Toughness
- Provide Uniformity of Performance

P/M Procedure:

- Remelt Wrought 440XH
- N2 Gas Atomize
- HIP
- Hot Roll

Comparison of MicroMelt 440XH Heat 182318 to Typical Wrought 440XH Analysis

<u>Element</u>	<u>MicroMelt Heat 182318</u>	<u>Typical Wrought 440XH</u>
C	1.55	1.60
Mn	.58	.50
Si	.37	.35
P	.013	.020 MAX.
S	.001	.005 MAX.
Cr	16.30	16.0
Ni	.36	.35
Mo	.82	.80
V	.42	.45
N	.114	.05

Experimental Procedure

Compare 440C & 440XH P/M & Wrought Products:

- Heat Treatment Response
- 95 F / 95% Humidity Corrosion Test
- Microstructure
- Toughness

Heat Treatment Response

Heat Treatment Response: Air Cool + Temper

<u>Temper</u>	<u>Hardness, HRC</u>			
	<u>Wrought 440C</u>	<u>Wrought 440XH</u>	<u>P/M 440C</u>	<u>P/M 440XH</u>
As-Quenched	60.0	62.0	60.0	62.0
250 F (1h)	60.0	62.5	61.0	62.5
350 F (1h)	58.0	60.5	60.0	60.5
450 F (1h)	56.5	58.5	58.5	59.5

Heat Treatment: 1925 F (25 mins.) Air Cool + Temper

Heat Treatment Response: Air Cool + Refrigeration + Temper

<u>Temper</u>	<u>Hardness, HRC</u>			
	<u>Wrought 440C</u>	<u>Wrought 440XH</u>	<u>P/M 440C</u>	<u>P/M 440XH</u>
As-Quenched	61.0	63.0	62.0	63.0
250 F (1h)	60.5	64.0	62.5	63.5
350 F (1h)	59.0	62.0	61.5	61.5
450 F (1h)	57.5	60.5	60.5	61.0

Heat Treatment: 1925 F (25 mins.) Air Cool +
-100 F (1h) A.W. + Temper

Heat Treatment Response: Oil Quench + Temper

<u>Temper</u>	<u>Hardness, HRC</u>			
	<u>Wrought 440C</u>	<u>Wrought 440XH</u>	<u>P/M 440C</u>	<u>P/M 440XH</u>
As-Quenched	60.5	62.0	60.0	62.5
250 F (1h)	61.0	62.5	61.0	63.0
350 F (1h)	58.5	60.0	59.5	61.0
450 F (1h)	57.0	58.0	58.0	59.5

Heat Treatment: 1925 F (25 mins.) Oil Quench + Temper

Heat Treatment Response: Oil Quench + Refrigeration + Temper

<u>Temper</u>	<u>Hardness, HRC</u>			
	<u>Wrought 440C</u>	<u>Wrought 440XH</u>	<u>P/M 440C</u>	<u>P/M 440XH</u>
As-Quenched	61.5	63.5	62.0	63.5
250 F (1h)	61.5	64.5	63.5	64.0
350 F (1h)	59.0	62.0	62.0	62.0
450 F (1h)	57.5	60.0	60.0	60.5

Heat Treatment: 1925 F (25 mins.) Oil Quench +
-100 F (1h) A.W. + Temper

Heat Treatment Response: 350 F Double Temper

<u>Treatment</u>	<u>Hardness, HRC</u>			
	<u>Wrought 440C</u>	<u>Wrought 440XH</u>	<u>P/M 440C</u>	<u>P/M 440XH</u>
Air Cool + Double Temper	58.5	62.0	61.0	62.0
Oil Quench + Double Temper	59.0	61.5	61.5	63.0

Heat Treatment: 1925 F (25 mins.) Air Cool or Oil Quench +
-100 F (1h) A.W. + 350 F (1h) A.C. +
-100 F (1h) A.W. + 350 F (1h) A.C.

Corrosion Rating System

Rating Number	% of Surface Rusted
1	No Rust
2	1 - 3 Rust Spots
3	5
4	5 - 10
5	10 - 20
6	20 - 40
7	40 - 60
8	60 - 80
9	>80

95°F/95% Humidity Corrosion Test Results

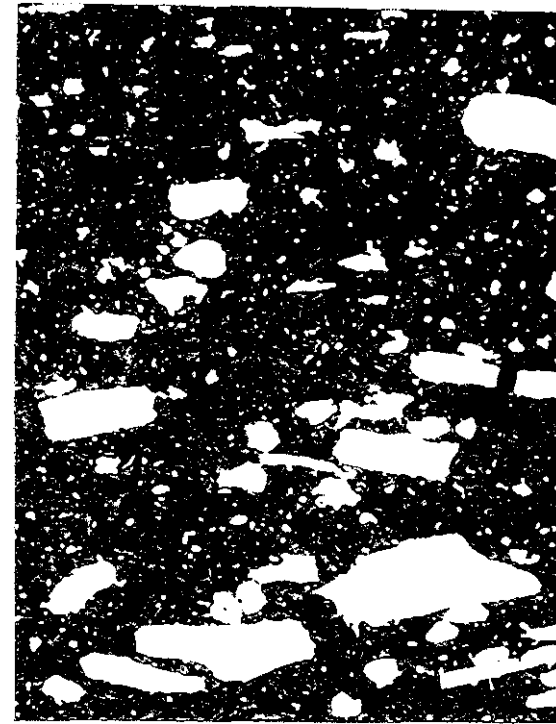
Corrosion Rating Numbers for

<u>Test Time (hours)</u>	<u>Wrought 440C</u>	<u>Wrought 440XH</u>	<u>P/M 440C</u>	<u>P/M 440XH</u>
1	1	1	1	1
8	1	1	1	1
24	1	1	1	1
72	1	1	1	1
150	1	1	1	1
200	1	1	1	1

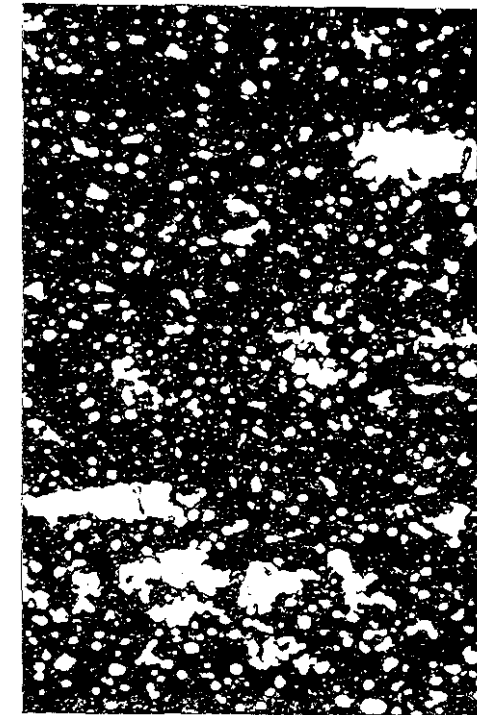
Heat Treatment: 1925 F (25 mins.) O.Q. +
-100 F (1h) A.W. + 350 F (1h) A.C. +
-100 F (1h) A.W. + 350 F (1h) A.C.

Microstructure Comparison

Cast/Wrought 440XH & Cast/Wrought 440C



Cast/Wrought 440XH

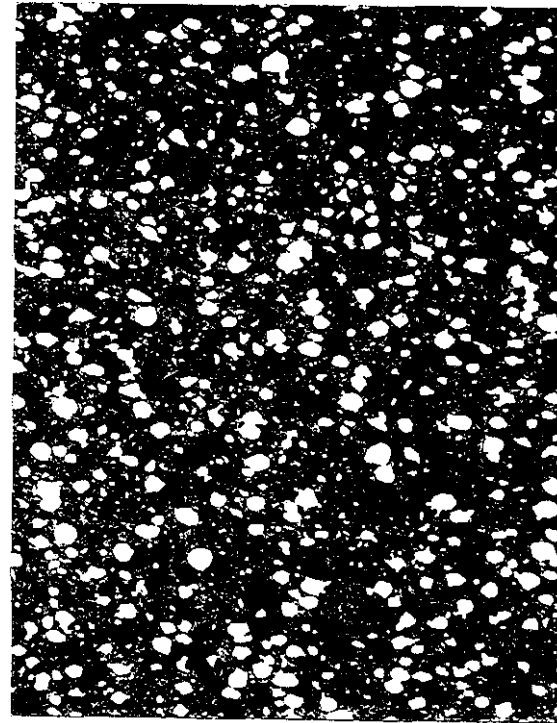


Cast/Wrought 440C

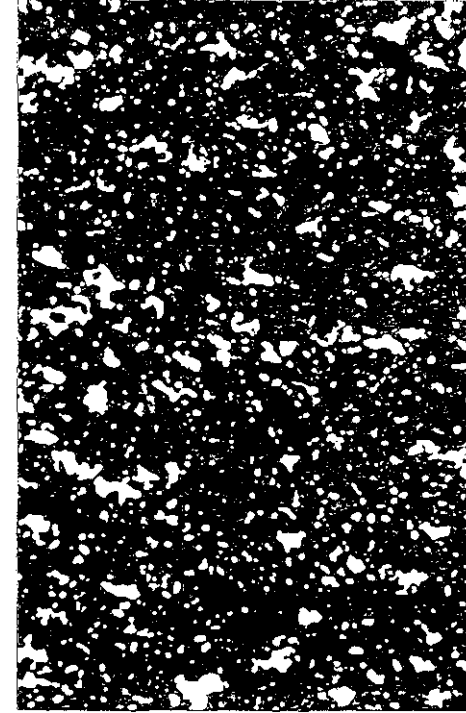
Heat Treatment: 1925 F (25 mins.) Oil Quench
-100 F (1h) A.W./ 350 F (1h) A.C. +
-100 F (1h) A.W./ 350 F (1h) A.C.

Original Magnification • 1000X; Longitudinal Orientation

P/M 440XH & P/M 440C



P/M 440XH

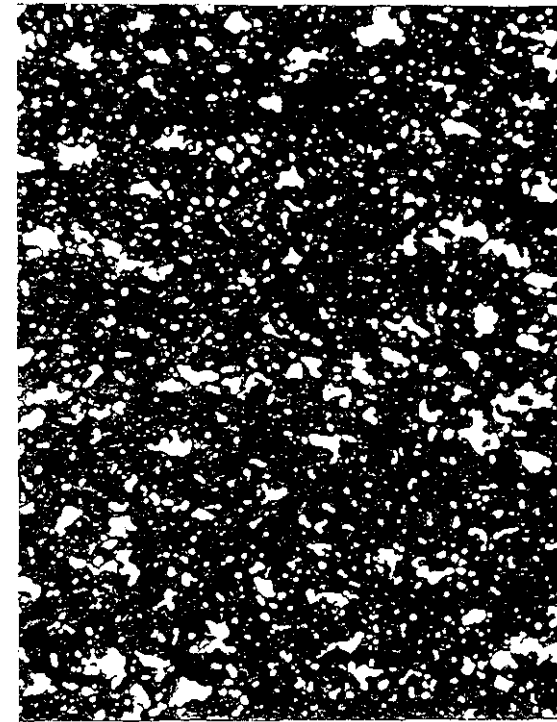


P/M 440C

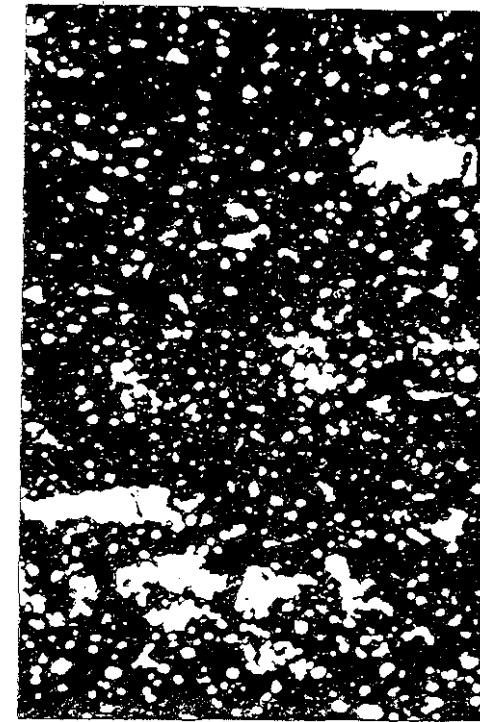
Heat Treatment: 1925 F (25 mins.) Oil Quench
-100 F (1h) A.W./ 350 F (1h) A.C. +
-100 F (1h) A.W./ 350 F (1h) A.C.

Original Magnification= 1000X; Longitudinal Orientation

P/M 440C & Cast/Wrought 440C



P/M 440C

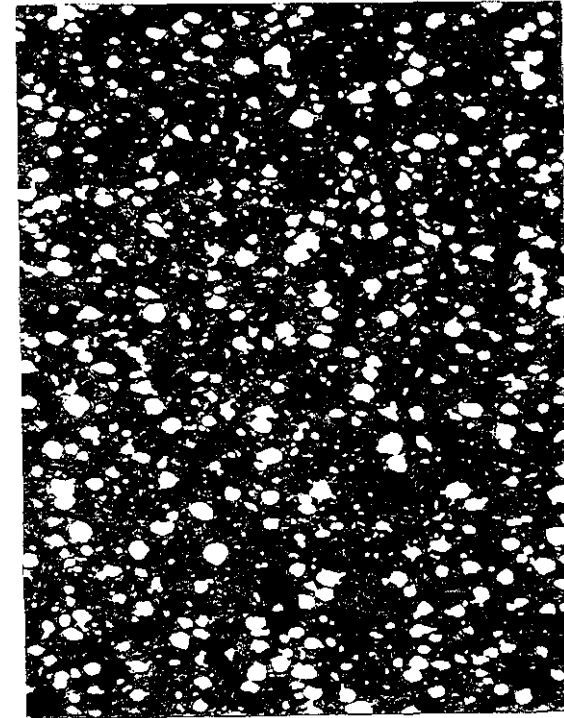


Cast/Wrought 440C

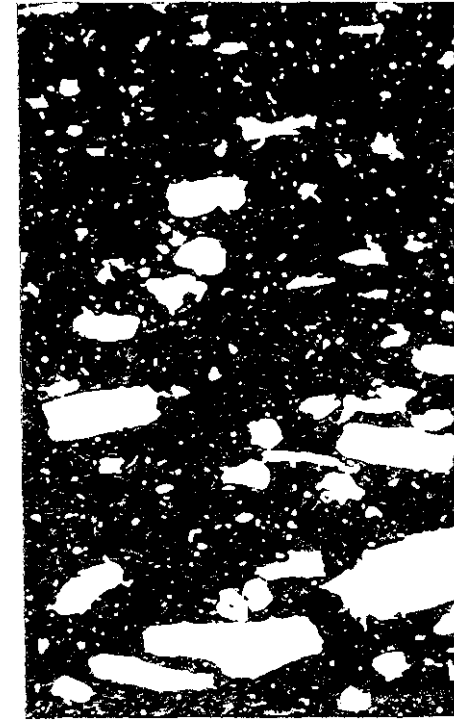
Heat Treatment: 1925 F (25 mins.) Oil Quench
-100 F (1h) A.W./ 350 F (1h) A.C. +
-100 F (1h) A.W./ 350 F (1h) A.C.

Original Magnification 1000X; Longitudinal Orientation

P/M 440XH & Cast/Wrought 440XH



P/M 440XH



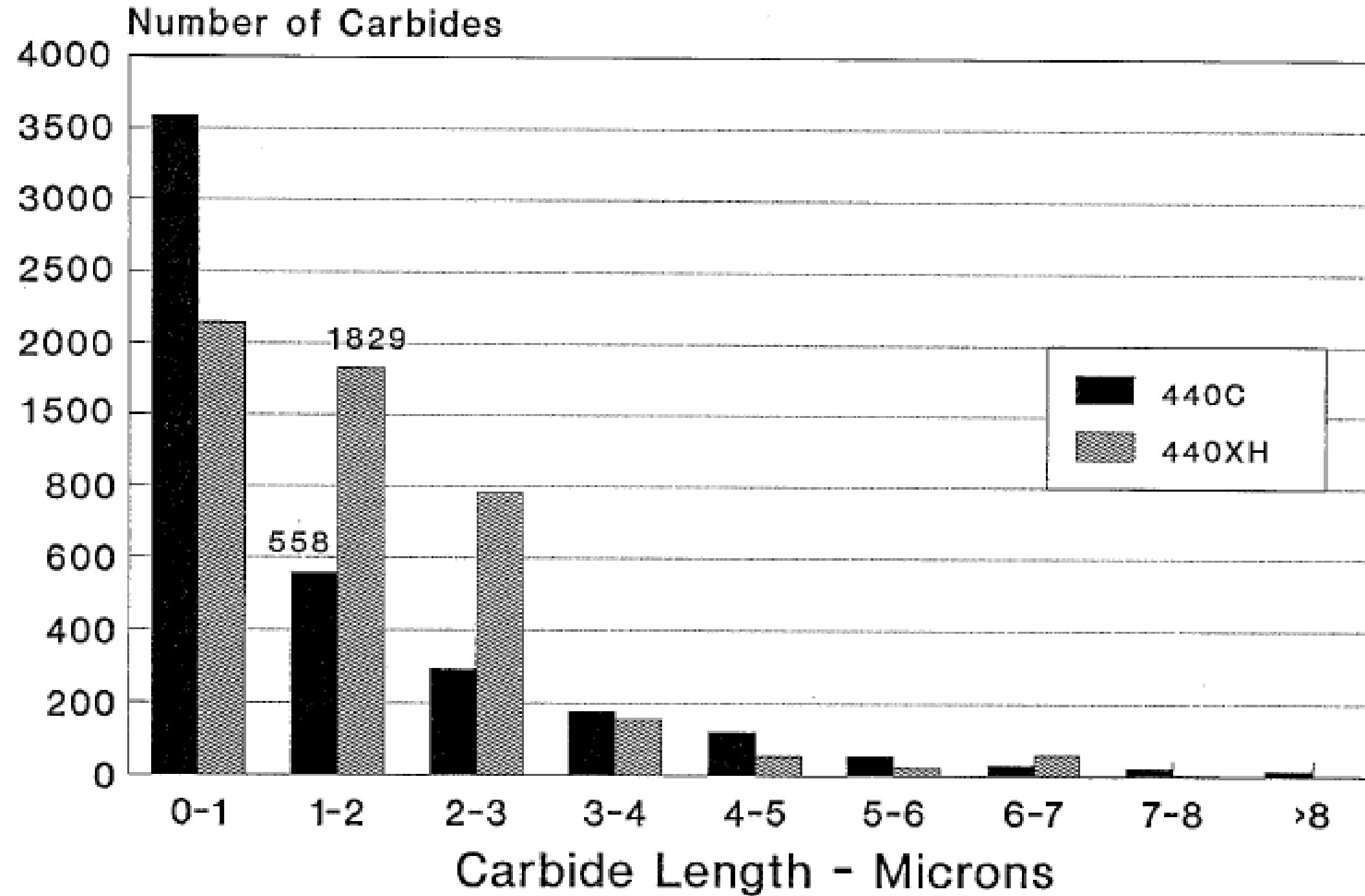
Cast/Wrought 440XH

Heat Treatment: 1925 F (25 mins.) Oil Quench
-100 F (1h) A.W./ 350 F (1h) A.C. +
-100 F (1h) A.W./ 350 F (1h) A.C.

Original Magnification 1000X; Longitudinal Orientation

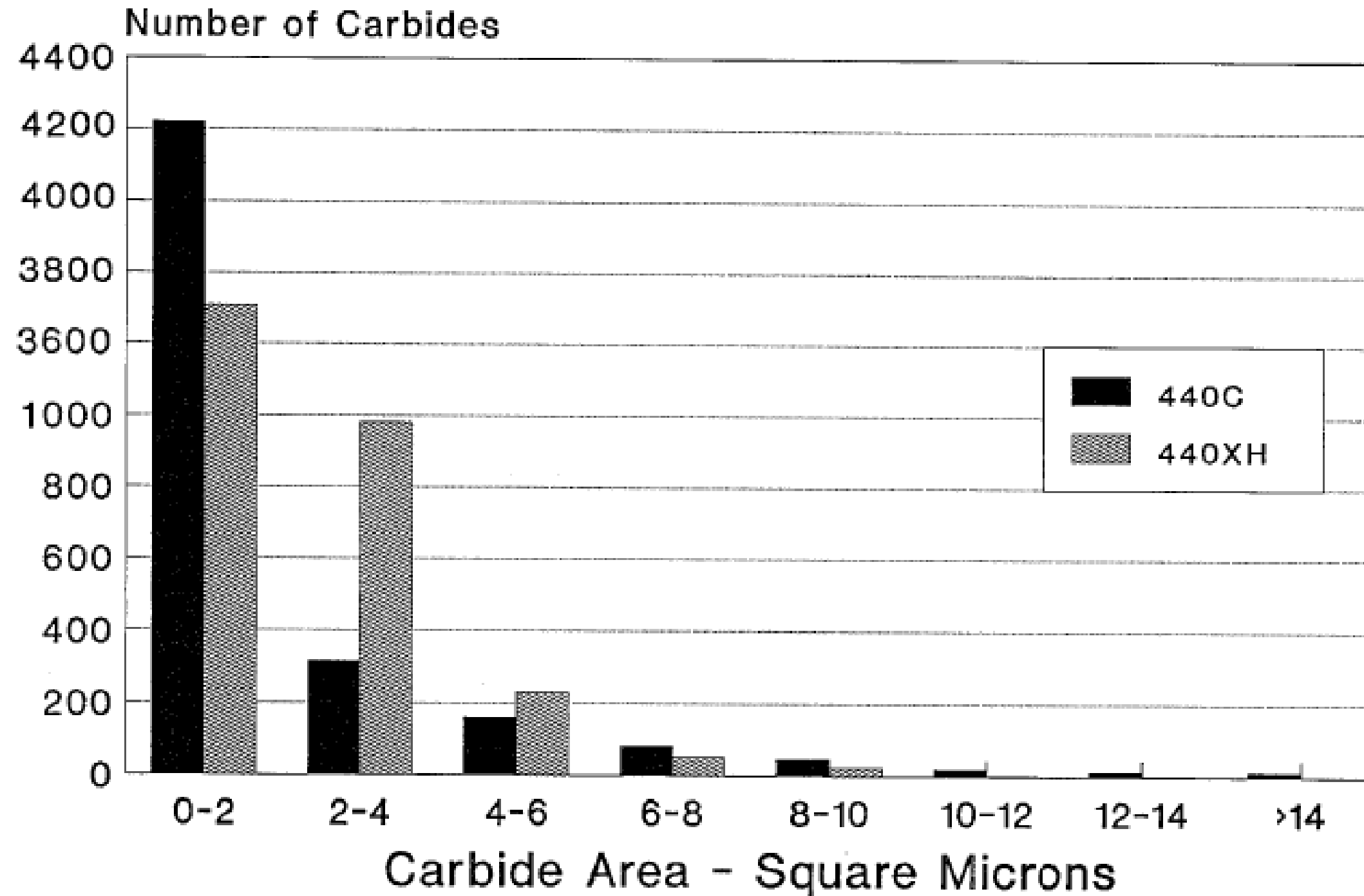
Carbide Length Distribution

P/M 440C vs. P/M 440XH



Carbide Area Distribution

P/M 440C vs. P/M 440XH



Toughness

Unnotched Izod Impact Toughness

<u>Alloy</u>	<u>Unnotched Izod Impact Energy (ft-lbs.)</u>
Wrought 440C	29, 24
Wrought 440XH	18, 18
P/M 440C	25, 30
P/M 440XH	30, 38

Longitudinal Orientation

Heat Treatment: 1925 F (25 mins.) Oil Quench +
-100 F (1h) A.W. + 350 F (1h) A.C. +
-100 F (1h) A.W. + 350 F (1h) A.C.

Conclusions & Summary

- P/M 440XH Hardness Response = C/W 440XH
- P/M 440XH Impact Strength >C/W 440XH
- P/M 440XH Corrosion Resistance = C/W 440XH
- P/M 440XH Microstructure Finer than C/W 440XH
- Additional Work Required to Optimize Composition of P/M 440XH
- Customer Evaluation is Required to Determine Performance & Marketability of P/M 440XH

Applications for 440XH

440C - Type Applications

- Bearing Assemblies (Balls & Races)
- Cutlery
- Needle Valves
- Ball & Check Valves
- Valve Seats
- Pump Parts
- Ball Studs
- Bushings

D2 - Type Applications

- Blanking Dies
- Forming Dies
- Extrusion Dies
- Drawing Dies
- Forming Rolls
- Edging Rolls
- Beading Rolls
- Master Tools
- Heading Tools
- Long Punches
- Intricate Punches
- Slitting Cutters